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TECHNICAL NOTE

D-786

INVESTIGATION OF THE LONGITUDINAL CHARACTERISTICS
OF A LARGE-SCALE JET TRANSPORT MODEL EQUIPPED
WITH CONTROLLABLE THRUST REVERSERS

By David H. Hickey, William H. Tolhurst, Jr.,
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Ames Research Center
Moffett Field, Calif.

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SUMMARY

An investigation was conducted to determine the effect of thrust control by means of controllable thrust reversers on the longitudinal characteristics of a large-scale airplane model with a 35° sweptback wing of aspect ratio 7 and four pylon-mounted jet engines. The model was equipped with target-type thrust reversers designed to provide thrust control ranging from full forward thrust to full reverse thrust. The use of thrust control in landing-approach configurations formed the major portion of the study. Results were obtained with both leading- and trailing-edge high-lift devices. Lift, drag, and pitching-moment coefficients and reverser effectiveness data are presented. Test Reynolds numbers ranged from 4.2 to 8 million.

Examination of the data indicates that thrust control by means of thrust reversers can bring about a deterioration of longitudinal characteristics when reverser closure is more than 40 percent. However, analysis indicates that with closure up to 40 percent the reversers can provide a significant improvement in landing approach performance.

INTRODUCTION

A study of the various characteristics of a typical subsonic jet transport model with a swept wing and four pylon-mounted nacelles has been conducted in the Ames 40- by 80-Foot Wind Tunnel. References 1 and 2 consider the low-speed aerodynamic characteristics of the model with high-lift devices, and reference 3, the exhaust gas ingestion characteristics with thrust reversers used for braking during the landing rollout. The subject investigation extended the transport model studies to the use of controllable reversers for in-flight thrust control. Reference 4 reports flight tests of this type of thrust control scheme on a fighter airplane in landing approach and reference 5 reports wind-tunnel tests of the effect of reverser operation on aerodynamic characteristics of a jet transport in the cruise Mach number range.

The present investigation was conducted to determine the effect of controllable reverser operation on the longitudinal characteristics of the model in the landing configuration. The basic configuration used for the tests had a 50° deflected flap with blowing boundary-layer control. Some data were obtained with leading-edge slats, trailing-edge flaps with and without boundary-layer control, flaps up, and symmetrical two-engine thrust reverser operation. Most of these results were obtained with one reverser configuration which was acceptable from the ingestion standpoint (ref. 3). However, several other reverser configurations were also investigated to a limited degree.

These results are analyzed to demonstrate the effect of using reversers for thrust control during the landing approach.

NOTATION

b	wing span, ft
BLC	boundary-layer control
c	chord, measured parallel to the plane of symmetry, ft
$\bar{c}$	mean aerodynamic chord, $\frac{2}{S} \int_0^{b/2} c^2 dy$, ft
C_D	drag coefficient, $\frac{\text{drag}}{qS}$
ΔC_D	change in drag coefficient due to engine and reverser operation
C_R	gross thrust coefficient, $\frac{F_g}{qS}$
C_L	lift coefficient, $\frac{\text{lift}}{qS}$
ΔC_L	change in lift coefficient due to engine and reverser operation
C_m	pitching moment computed about $0.30 \bar{c}$, $\frac{\text{pitching moment}}{qS\bar{c}}$
C_μ	momentum coefficient, $\frac{W_j/g}{qS} V_j$
d	engine tail-pipe diameter, in.
D	drag, lb

F_n	net thrust from engine
F_g	gross thrust from engine
g	acceleration of gravity, 32.2 ft/sec ²
Δi_t	change in stabilizer angle for trim, deg
l	distance between reverser targets, in.
LE	leading edge
q	dynamic pressure, lb/ft ²
S	wing area, sq ft
T	temperature, °R
TE	trailing edge
V	velocity, ft/sec or knots
V_s	stalling speed
W	gross weight, lb, or weight rate of flow, lb/sec
x	distance along airfoil chord parallel to the plane of symmetry
y	spanwise distance perpendicular to the plane of symmetry, ft
z	perpendicular distance above the extended wing-chord plane, ft
α	angle of attack of fuselage reference line, deg
β	reverser end-plate angle with respect to the line of symmetry, deg
δ	ratio of standard day barometric pressure to ambient pressure
δ_f	flap deflection measured normal to the flap hinge line, deg
δ_s	slat deflection
ϵ	reverser tilt angle with respect to the vertical, deg
η	wing semispan station, $\frac{2y}{b}$
θ	flight path angle with respect to the horizontal, deg, or ratio of standard day temperature, to ambient temperature, °R
ω	reverser rotation angle, positive clockwise when viewed from upstream, deg

Subscripts

ap	approach
e	engine
j	flap jet
l	lower
max	maximum
u	upper
∞	free stream

MODEL AND APPARATUS

Figure 1 is a photograph of the model installed in the 40- by 80-foot wind tunnel. Pertinent dimensions of the model are given on figure 2.

Reverser

The thrust reversers used for the investigation were the angled target type, with variable angle end plates. Details of the reverser geometry are shown in figure 3(a). Figure 3(b) presents photographs of the inboard reverser. Both the main target and the end plates were contoured to retract into the conical afterbody of a nacelle. The plates at the top of the reversers provided protection for the wing lower surface. For this investigation, the main targets were rotated around a fixed axis. The geometry of the reverser positions tested is listed in table I.

During the investigation reported in reference 3, several reverser configurations with acceptable ingestion characteristics were developed. Four of these configurations were selected for study in the present investigation. These configurations are described in table I and figure 3. The configuration on which most data were obtained in the present investigation is denoted as number 2 in table I. Modifications to improve ingestion characteristics were (1) inboard reversers tilted 3° to produce a downward flow, (2) outboard reversers tilted 3° to produce an upward flow, and (3) tabs as described on figure 3 and table I.

The reverser target positions are defined by the tail-pipe diameter minus the distance between the reverser targets in percent of tail-pipe diameter $\left[100\left(1 - \frac{l}{d}\right)\right]$. This parameter is representative of the relative closure of the reversers.

Wing

The aspect ratio 7 wing had a 0.3 taper ratio, 35° of sweepback at the quarter-chord line, 6° of dihedral, and 2° of incidence. An NACA 65-A414 airfoil section was employed at the root, with a straight taper to the NACA 65-A410 section at the tip (see table II for coordinates).

A leading-edge slat was contained in the wing. Figure 4 shows a typical slat-wing cross section, and table III lists the slat coordinates. Slat breaks at each engine pylon were provided, so that each segment of the slat could be individually extended. When the slat was extended, it was deflected 15° from the wing chord plane. Unless otherwise specified, all three slat segments were deflected together. The terminology "plain leading edge" as used in this report refers to configurations for which the leading-edge slats are retracted.

Trailing-Edge Flap System

Figure 5 shows the wing-flap geometry and a typical cross section of the flap.

The trailing-edge flap was designed to use the aft 40 percent of the wing. Accordingly, the plain flap was hinged at 68 percent chord, and the boundary-layer control (BLC) ducting was placed within the flap. The blowing nozzle was fixed 55° from the wing chord line on the flap radius. The two flap spanwise segments extended from 9 to 34, and 44 to 63 percent semispan. Further details of the trailing-edge flap system are given in reference 2.

Fuselage

The fuselage cross section was defined by a 4- by 5-foot ellipse, except for the nose and tail cone. The nose section was one-half of a 4- by 8-foot ellipse in the horizontal cross section and a 5- by 8-foot ellipse in the vertical cross section. The tail cone had a straight taper from a 4- by 5-foot ellipse to a similar but smaller ellipse at the tail.

Nacelles and Pylons

Engine nacelles and pylons were attached to the wing at 40 and 70 percent semispan. The engine nacelles housed J-30 engines. The engine center lines were 28 inches below the wing chord plane.

TESTING AND PROCEDURE

Force and moment data were obtained through an angle-of-attack range from -4° to $+19^{\circ}$. Testing was conducted at free-stream airspeeds of 115 to 203 feet per second, corresponding to Reynolds numbers of 4.8 to 8.0×10^6 , and dynamic pressures of 15 to 50 pounds per square foot.

Tests with constant C_{μ} , engine thrust, and varying angle of attack.-

When angle of attack was varied with boundary-layer control operating, C_{μ} was maintained at 0.014 , a level adequate to keep attached air flow on the flap. Engine mass flow was maintained at a constant value through the angle-of-attack range. Angle of attack was varied with engine thrust and wind-tunnel dynamic pressure held constant. Data were obtained for several flap deflections, reverser configurations, and leading-edge configurations.

Tests with constant angle of attack and varying throttle setting.-

The thrust calibrations of the reverser configurations were obtained at a wind-tunnel dynamic pressure of 10 pounds per square foot. Force data were measured with the flaps undeflected at several rpm for each engine independently. Gross thrust for the engine-reverser combination was then taken as the measured drag corrected for ram drag and model power-off drag.

CORRECTIONS

The following corrections were applied for the effect of wind-tunnel boundaries:

$$\alpha = \alpha_u + 0.59 C_L$$

$$C_D = C_{Du} + 0.010 C_L^2$$

$$C_m = C_{mu} + 0.0028 C_L$$

PRESENTATION OF TEST RESULTS

Figures 6 through 16 summarize the experimental results of this investigation.

Figure 7 shows three-component force data illustrating the power-off longitudinal characteristics of the model with and without high-lift devices. Figures 8 through 12 show the effect of reverser operation on longitudinal characteristics of the model. Figure 8 shows the effect of power and reverser setting on the basic configuration (plain leading edge, $\delta_f = 50^\circ$ with BLC); figure 9, typical characteristics with and without flaps and boundary-layer control; and figure 10, typical characteristics with and without leading-edge slats. Figures 11 and 12 contain data showing the effect on longitudinal characteristics of reverser configuration and symmetrical two-reverser operation.

Data presented in references 3 and 6 indicate that the flow field of the free stream and reversed gases is defined by the ratio of the momentum of the reversed gases to the momentum of the free stream. The value of this ratio is comparable to the more familiar term, thrust coefficient (C_R herein). Thus, the aerodynamic coefficients of the model are a function of thrust coefficient for the range of test variables (Mach number and engine pressure ratios) considered in references 3 and 6. Since the present investigation covered the same range of variables, this principle was used in the presentation in figures 13 through 16 of lift, drag, and moment coefficients, all at $\alpha = 0^\circ$, and maximum lift coefficient as a function of gross thrust coefficient. Figure 13 presents results with and without flaps deflected and with and without boundary-layer control. Figure 14 presents results with several different combinations of leading- and trailing-edge devices and one reverser closure; figure 15 presents results for several reverser configurations with one reverser closure; and figure 16 presents results for symmetrical two-engine operation.

DISCUSSION

A discussion of the effect of controlled reverser operation on the aerodynamic characteristics of the model follows. The experimental results were used to ascertain the effect on longitudinal characteristics of thrust control by means of reversers.

The term "maximum lift coefficient," as employed in the following discussion is defined as the lift coefficient at which neutral longitudinal stability occurs; increasing lift above this value causes longitudinal instability.

Effect of Engine and Reverser Operation on Lift

General results.-- Examination of the results presented in figures 8 through 16 shows that with the trailing-edge flap deflected, maximum lift, flap lift increment, and lift-curve slope were reduced at most engine powers tested with the reversers at closures greater than 40 percent. As shown by comparison of results presented in figures 7(a) and 8(a), with 40-percent reverser closure the lift and moment characteristics were virtually unaffected throughout the range of thrust coefficients tested. The reduction of maximum lift that occurred at the larger reverser closures was caused both by a reduction of the angle of attack for $C_{L_{max}}$ (tuft studies showed air-flow separation at the wing leading edge caused by spillage of turbulent reversed exhaust gases over the wing upper surface) and by a reduction of flap lift increment. Since lift at 0° angle of attack was lost only when the flap was deflected, the loss is probably due to a reduction of pressure on the lower surface of the flap caused by the reversed exhaust gases. When devices were employed to increase maximum lift, the lift reduction due to reverser operation also increased. It was, however, possible to correlate the data obtained with different model configurations to a degree. Figure 17 presents data showing the variation with gross thrust coefficient of the ratio of power-on maximum lift with reversers to power-off maximum lift. This ratio is shown for the four reverser closures tested with and without BLC on the trailing-edge flap. With reverser closures of 58 and 79 percent, the effect of BLC on the maximum lift ratios is within the experimental scatter; with 40 percent closure, there is little effect of thrust reversal, so that the ratios should be equivalent. Data in figure 18 show the same lift ratios, with 79-percent closure, for several combinations of leading- and trailing-edge high-lift devices. Maximum lift ratios for the various configurations agreed within 10 percent. The results noted above also generally apply to the lift ratios at 0° angle of attack (also shown in figs. 17 and 18). The correlation of these ratios indicates that the test results can be interpolated or extrapolated to other conditions with some degree of confidence. In the subsequent analysis of the effect of reverser thrust control on performance, it was necessary to use the maximum lift ratios to extend the data.

Effect of reverser configuration on lift.-- Typical longitudinal characteristics with several reverser configurations and 79-percent closure are shown in figure 11. All data are for the same power setting. Removing the ingestion tabs on the reverser end plate (required to control ingestion during the landing rollout, ref. 3), reduced maximum lift and lift-curve slope below that obtained with the other reverser configurations. However, as shown in figure 6, removal of the tabs nearly doubled reverse thrust with 79-percent closure. As shown in figure 15, if results were compared at equivalent gross thrust coefficients, the longitudinal characteristics would be about the same. Rotation or additional tilt of the reversers caused only small changes in longitudinal characteristics (fig. 11).

Effect of symmetrical two-engine operation.-- Figure 12 and 16 show the effect on longitudinal characteristics of thrust control with symmetrical two-engine operation. With the same weight-flow per engine, operation of only the inboard engines caused essentially the same lift loss as when all engines were operating (fig. 12). With operation of only the outboard engines, the decrement of maximum lift was 40 percent of the decrement when all engines were operating, engine power settings being equal. Although this result seems favorable, results compared at the same gross thrust coefficient (comparable drag force) show less favorable results. For an example, as shown in figure 14, with the plain leading edge, 79-percent closure, and a thrust coefficient of -0.03 , the maximum lift coefficient with two engines is 1.33 and with four engines, 1.32.

The Effect of Reverser Operation on Drag

The effect of trailing-edge flaps on drag increment due to reverser operation.-- Data in figure 19 show the effect of reverser operation on the model drag coefficient. Incremental model drag coefficient is shown as a function of gross thrust coefficient. The effect of flap deflection and C_{μ} on the drag increment variation is shown in figure 19(a) for all reverser closures tested. Except for the 40-percent closure position, reverser operation gave a much larger drag increment with flaps undeflected than with the flaps deflected. If a reduction of positive pressure on the flap lower surface occurs, as suggested in the preceding discussion of engine-reverser operation effects on lift, aerodynamic drag of the model would be reduced also. Boundary-layer control on the trailing-edge flap had little effect on the drag increments due to reverser operation.

Effect of reverser configuration on drag increment due to reverser operation.-- Figure 19(b) presents data showing the effect of the end-plate tabs (required to reduce exhaust-gas ingestion) on the incremental variation of drag coefficient with gross thrust coefficient. It should be noted (fig. 6) that a higher percentage of thrust reversal was obtained without the end-plate tabs. With the flaps undeflected, the variation of incremental drag coefficient with gross thrust coefficient was nearly equal with and without tabs. With the flaps deflected, the incremental model drag coefficient was much larger with the end-plate tabs than without. This difference may be explained by the effect of the reversed exhaust flow on the aerodynamic drag of the model. The main function of the end-plate tabs is to separate the exhaust flow into upper and lower segments; the result of this is that the reversed exhaust flow no longer completely shields the flap from the free stream air flow, so that the flap has a higher drag with tabs than without.

In summary, although modifications to the reverser to delay exhaust gas ingestion during the landing rollout may reduce the static value of reversed thrust, when an aircraft with wing-mounted nacelles is considered with the flaps deflected, the over-all drag of the aircraft will probably

be larger with than without the ingestion modifications. Furthermore, with flaps deflected the total drag will probably be less than the sum of the static reversed thrust and aerodynamic drag. These remarks apply only to aircraft with configurations similar to that of the model.

Effect of Reverser Operation on Stability and Pitching Moments

As evidenced by the data in figures 8 through 12, neither engine power nor reverser operation caused a significant change in stability as long as the flow at the wing leading edge remained attached. When leading-edge separation occurred, as indicated by a change in lift-curve slope or by a drag rise, reverser operation did, in certain cases, cause a reduction or loss of stability. The lack of sensitivity of longitudinal stability to changes in power and reverser closure indicate that reverser operation did not materially affect dynamic pressure at the tail or the variation of downwash at the tail with angle of attack when smooth flow existed over the wing.

The pressure reduction on the lower surface of the flap (noted earlier) would be expected to cause nose-up pitching moments. Examination of the pitching-moment data at 0° angle of attack, shown in figures 13 through 16, confirms the existence of this nose-up pitching moment at the appropriate reverser closures. It should be noted that the pitching-moment change associated with actuation of the reversers in the 58 to 100 percent closure range would tend to rotate the airplane to higher angle of attack and thus gain back the lift loss due to reverser actuation.

Effect of Reverser Operation on Flight Characteristics

Landing approach with controllable reversers.—Reference 4 reported results of flight tests with a controllable reverser on a fighter type aircraft. It was reported that the improved precision of control and thrust response made available with a controllable reverser greatly increased the pilot's ability to fly a precise landing approach path even at high angles of descent. Specifically, gains that can be realized from reverser operation are: (1) more accurate control of touchdown point because of increased glide path angle, improved precision of speed and flight path control, and ability to control ground buoyancy effects, (2) improved wave-off characteristics due to the reduced time required to attain full forward engine thrust, and (3) reduction in ground roll distance because of the improved thrust response made possible by the higher power setting and the partial closure of the reverser at touchdown.

In the fighter aircraft reverser installation, only longitudinal trimming characteristics were affected by reverser operation; whereas in this particular jet transport reverser installation, the basic longitudinal aerodynamic characteristics (maximum lift, stability, etc.) were altered by reverser operation. If, however, adequate thrust control is available from the reversers at closures where longitudinal characteristics are not significantly affected, gains similar to those previously cited in

reference 4 may be available. Calculations were made, on the basis of data presented herein, to determine to what extent reversers could be used to control flight path angle during the landing approach of a typical jet transport aircraft. Two aircraft configurations were considered in the calculations, one with conventional high-lift devices and an approach speed ($1.3 V_S$) of 140 knots; the other with more effective high-lift devices and an approach speed of 120 knots. It was necessary to use the maximum lift ratios, discussed earlier, to interpolate and extrapolate the test results. Figure 20 shows the calculated variation of approach-speed margin ($1.3 V_S$ when reversers are inoperative) and change in stabilizer angle for trim as a function of steady-state descent angle. The descent angle at each of the four power settings is assumed to be controlled by the reversers. These curves are at a constant airspeed (constant C_L), so that a reduction in approach-speed margin as angle of descent increases signifies a reduction in maximum lift caused by exhaust gas flow. The incremental stabilizer angles presented indicate the change in stabilizer angle required to rotate the airplane to the angle of attack required to produce the lift coefficient that corresponds to the specified approach speed. Some results of the calculations are tabulated below.

V = 140 knots				
Power setting, percent	1.3 V_S		1.275 V_S	
	θ	Δi_t	θ	Δi_t
35	8.1	0.6	9.8	1.0
50	7	.7	9.0	1.0
75	4.5	.8	7.4	1.3
100	1.9	.8	5.4	1.5
V = 120 knots				
30	8.4	0	9.8	0
50	6.2	0	8	0
75	3.7	0	5.4	0
100	1	0	2.4	0

If a constant approach-speed ratio is assumed, the results from figure 21 and the table can be evaluated in two ways: For equal power settings, an increase in glide slope is available with a reverser compared to the slope without a reverser or, for the same glide slope, an increase in power setting is possible when a reverser is used. The first evaluation shows the magnitude of variation of flight path angle available from reversers and the second shows the possible improvement in thrust response (thrust response is more rapid at high power settings than at low power settings). The results presented in figure 20 are replotted in figure 21

to facilitate the evaluation. Figure 21 shows the variation of descent angle with power setting for several reverser closures. For the aircraft with the 140-knot approach speed and no reverser closure, 35 percent of the available thrust is required for a 3° descent angle; for the aircraft with the 120-knot approach speed, 30 percent of the available thrust is required. At these throttle settings, the use of controllable reversers allows the angle of descent to be increased by a factor of 2.7 without a reduction in approach-speed margin, thrust response, or an increase in approach speed. These approach angles (8.1°) are nearly as steep as those with the engines idling without reversers (in fig. 20), but without the loss in thrust response. If a 3° glide slope is considered, controllable reversers allow the engine power setting to be increased by a factor of 2.6 before approach-speed margin is affected.

These calculations show that controllable reversers can be used during the landing approach over a wide range of power settings and approach angles without a deterioration of aerodynamic characteristics. It can then be anticipated that with the improved thrust response and precise control made available with controllable reversers, the improvements in landing approach noted with the fighter reverser installation would be available on a jet transport aircraft. Because of the many factors which influence approach speed and handling characteristics, qualitative and quantitative assessment of gains possible in landing approach performance due to controllable reversers can best be made by flight tests of a controllable reverser installation on a jet transport aircraft.

Descent from cruising altitude.— An important use of thrust reversers would be during an emergency descent from cruise altitude. Results obtained from an emergency descent with a KC-135 are presented in reference 7. An average rate of descent of 6,300 feet per minute was obtained with engines at idle, landing gear and speed brakes extended, and a constant 0.83 indicated Mach number. Results presented in reference 5 show that between 20,000 and 30,000 feet of altitude, a rate of descent of about 7,000 ft/min can be raised to about 17,000 ft/min by using reversers for braking. Reference 7 shows that 20 seconds were required to extend all of the braking devices and initiate the descent; with thrust reversers, the time for reversers actuation would be much less. Thus the reduction of time before the descent is initiated and the increase in descent rate available with reversers should greatly reduce the time at higher altitudes. This reduction in time would reduce the possibility of injury to passengers during sudden decompression.

CONCLUDING REMARKS

Wind-tunnel tests of the longitudinal characteristics of a typical four-engine swept-wing jet transport model with wing-mounted engines and equipped with fully controllable target-type thrust reversers indicated

that for any throttle setting the reversers could be used with closures up to 40 percent (thrust of approximately 70 percent of the unreversed value) without causing a deterioration of longitudinal characteristics. Further reductions in forward thrust by use of the reverser cause a reduction in maximum lift.

Analysis of these data shows that when controllable reversers are used, landing approaches can be performed with 2-1/2 times the power setting of a conventional aircraft, resulting in improved thrust response and precision of thrust control; or, for the same power setting and thrust response, the approach angle can be 2.7 times larger.

Ames Research Center

National Aeronautics and Space Administration
Moffett Field, Calif., Jan. 17, 1961

APPENDIX

CALCULATION OF APPROACH-SPEED MARGIN

Some descent and approach performance characteristics of a transport airplane having the same configuration as the model were calculated to determine the practicability of controllable reverser operation. A wing area was assumed to be 2,430 square feet and the maximum gross thrust, 62,000 pounds (for four engines). To make the estimation it was necessary to assume that the maximum lift ratios presented herein are valid, and that the gross thrust coefficient adequately defines the aerodynamic characteristics of the aircraft. Civil regulations dictate an approach speed of $1.3 V_S$; thus the approach speeds used in the calculations, 140 and 120 knots, define the assumed stall speed and maximum lift of the aircraft.

The ratio of maximum lift with power on and reversers operative to maximum lift with power off was found to be generally independent of airplane configuration (see figs. 17, and 18, and discussion), so that it is possible to estimate the effect of reverser operation during landing approach on any geometrically similar aircraft if the approach speed is known. For the calculation with 140 knots approach speed, the data on figure 13(b) were adjusted to a power-off maximum lift coefficient of 1.65, keeping the same maximum lift ratios (C_L during approach was $0.592 C_{L_{max}}$). The power-off drag coefficient at 0° angle of attack and 50° flap deflection was adjusted to that measured in flight and presented in reference 8. For the calculation with 120 knots approach speed, the maximum lift data of figure 13(c) was similarly adjusted to a power-off maximum lift coefficient of 2.25. The drag coefficient at 0° angle of attack was increased by addition of the amount shown to be due to 50° of BLC flap deflection to the measured drag with flaps up presented in reference 8.

With these modifications to the data it was possible to calculate the reduction in approach-speed margin $(C_{L_{max}}/C_{L_{ap}})^{1/2}$ for a given power setting and reverser closure. As approach speed was maintained constant ($C_{L_{ap}} = \text{constant}$), when maximum lift was reduced by reverser operation, approach-speed margin was also reduced. The variation of the approach-speed margin with descent angle was calculated for the two airspeeds.

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TABLE I.- REVERSER CONFIGURATIONS TESTED

Configuration ¹	Percent closure, $\left(1 - \frac{l}{d}\right) \times 100$	β , deg	Engine 1			Engine 2			Engine 3			Engine 4		
			Tabs	ϵ	ω	Tabs	ϵ	ω	Tabs	ϵ	ω	Tabs	ϵ	ω
1	79	25	none	0	0	none	0	0	none	0	0	none	0	0
	100	30	none	0	0	none	0	0	none	0	0	none	0	0
2	40	6	4,6	-3	0	1,7	3	0	1,8	3	0	4,6	-3	0
	58	16	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
	79	25	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
	100	30	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
3	79	25	4,6	-6	0	1,7	6	0	1,8	6	0	4,6	-6	0
4	79	25	4,6	0	-15	1,2,7	0	-15	1,2,8	0	15	4,6	0	15

¹See figure 3 for definition of geometry

TABLE II.- COORDINATES OF BASIC WING PARALLEL TO THE MODEL PLANE OF SYMMETRY

x_u/c	z_u/c		x_l/c	z_l/c	
	$\eta = 0$	$\eta = 1.0$		$\eta = 0$	$\eta = 1.0$
0	0	0	0	0	0
.00347	.01178	.00842	.00653	-.00945	-.00675
.0058	.01442	.0103	.00920	-.01115	-.00797
.01059	.01853	.01323	.01441	-.01353	-.00967
.02283	.02606	.01862	.02717	-.01738	-.01242
.04757	.03765	.02689	.05243	-.02290	-.01636
.07247	.04678	.03342	.07753	-.02700	-.01928
.09746	.05451	.03893	.10254	-.03038	-.02170
.14757	.06698	.04784	.15243	-.03557	-.02541
.19781	.07656	.05468	.20219	-.03941	-.02815
.24811	.08392	.05994	.25189	-.04215	-.03011
.29846	.08934	.06382	.30154	-.04398	-.03142
.34884	.09299	.06642	.35116	-.04493	-.03209
.39923	.09495	.06782	.40077	-.04497	-.03212
.44962	.09495	.06782	.45038	-.04385	-.03132
.50000	.09290	.06636	.50000	-.04143	-.02959
.55035	.08869	.06335	.54965	-.0376	-.02685
.60064	.08266	.05904	.59936	Linear	Linear
.65086	.07513	.05367	.64914	↓	↓
.70101	.06634	.04738	.69899		
.75107	.05655	.04039	.74893		
.80103	.04591	.03279	.79897		
.85090	.03470	.02478	.84910		
.90066	.02309	.01649	.89934		
.95033	.01150	.00822	.94967		
1.00000	0	0	1.00000	0	0

TABLE III.- COORDINATES OF INSIDE SLAT¹ AND WING PARALLEL TO THE MODEL PLANE OF SYMMETRY

[Outside coordinates are the same as those in Table I]

x/c	$z/c; \eta = 0$		$z/c; \eta = 1.0$	
	Slat	Wing	Slat	Wing
0.02262	-0.01592	-0.01592	-0.01183	-0.01183
.02283	-.01213	-.01460	-.00908	-.01045
.04757	.01873	.01345	.01320	.00935
.07247	.03284	.02945	.02365	.02063
.09746	.04505	.04266	.03190	.02943
.14757	.06526	.06526	.04510	.04318

¹Slat trailing edge at $x/c = 0.1555$

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A-25586

Figure 1.- Photograph of the model as mounted in the Ames 40- by 80-Foot Wind Tunnel.

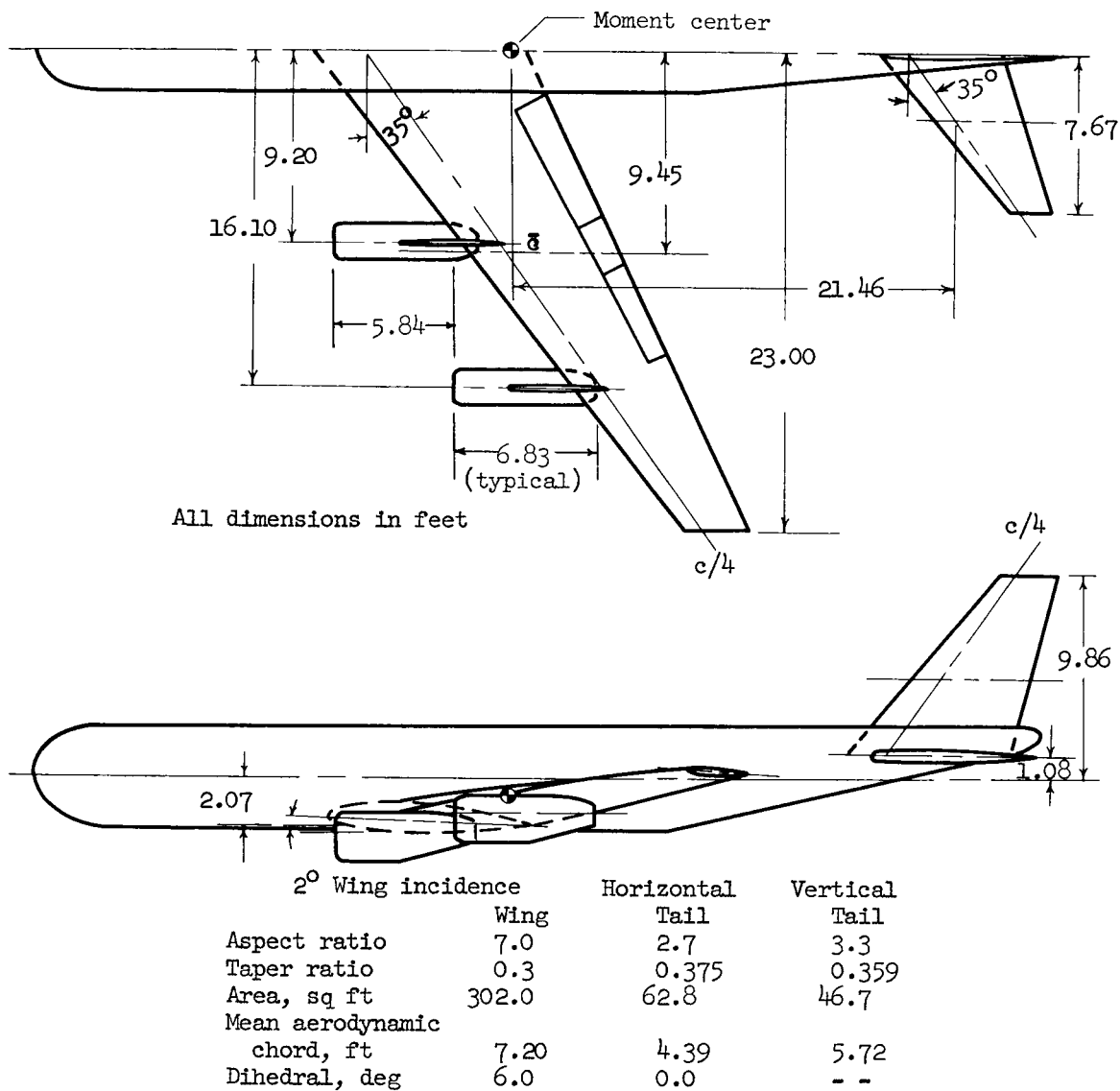
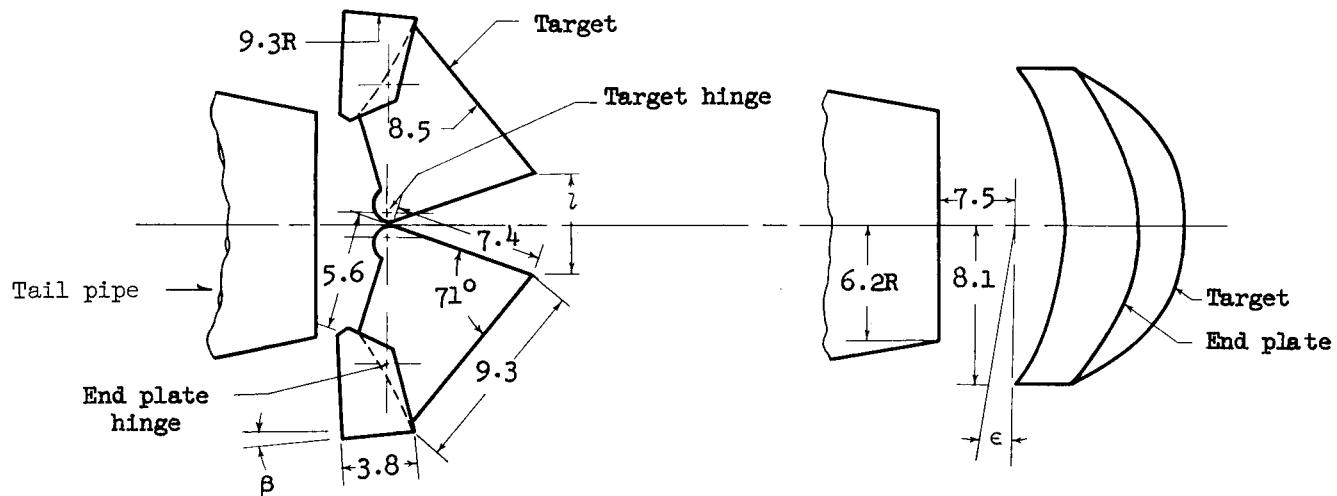


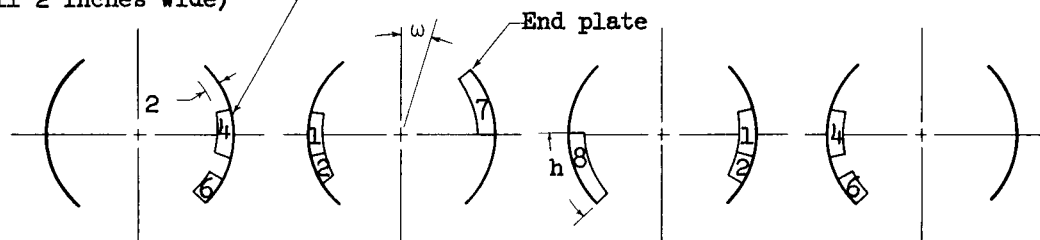
Figure 2.- Geometric details of the model.



All dimensions in inches

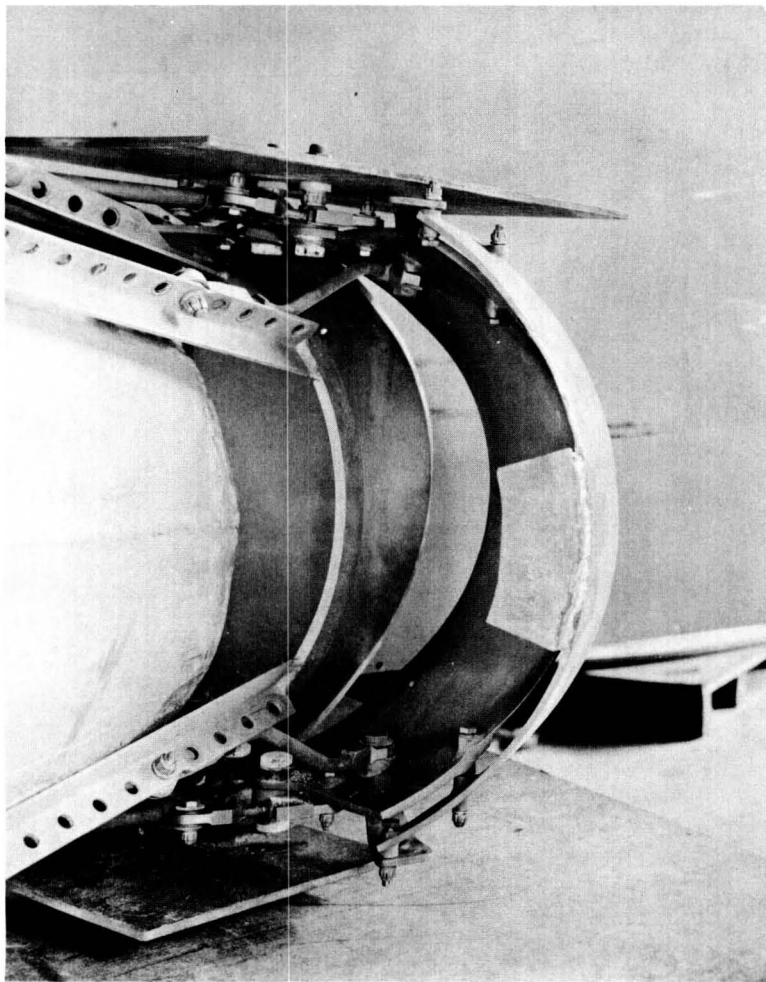
Tab	h, inches
1	5
2	3
4	5
6	3
7	9
8	9

Tabs (all 2 inches wide)



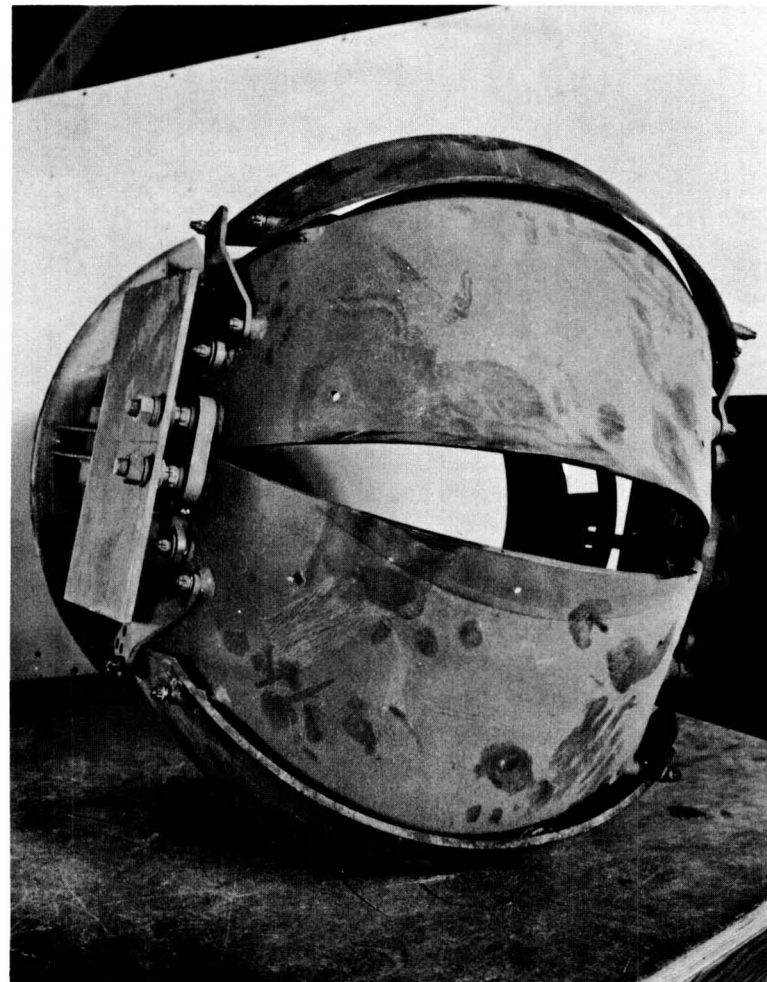
(a) Details of the reverser geometry.

Figure 3.- Details of the reversers.



Outboard side of inboard engine.

A-27246

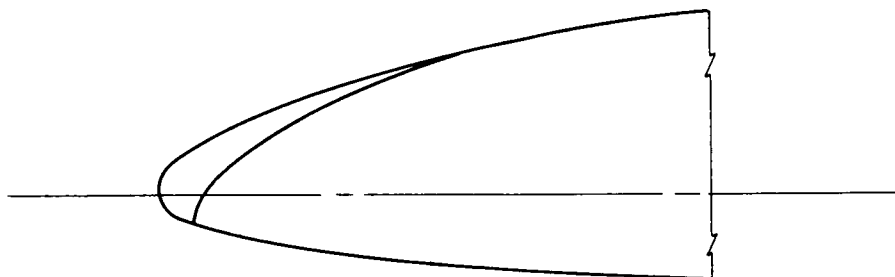


Rear view of reverser.

A-27247

(b) Photographs of the thrust reverser.

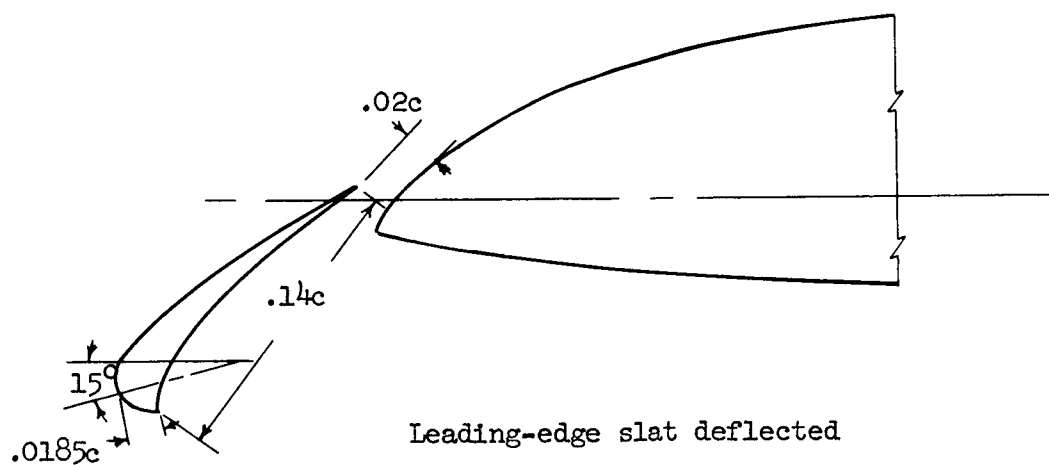
Figure 3.- Concluded.



Airfoil section (streamwise)

Root NACA 65A-414

Tip NACA 65A-410



Leading-edge slat deflected

Figure 4.- Details of the leading-edge slat.

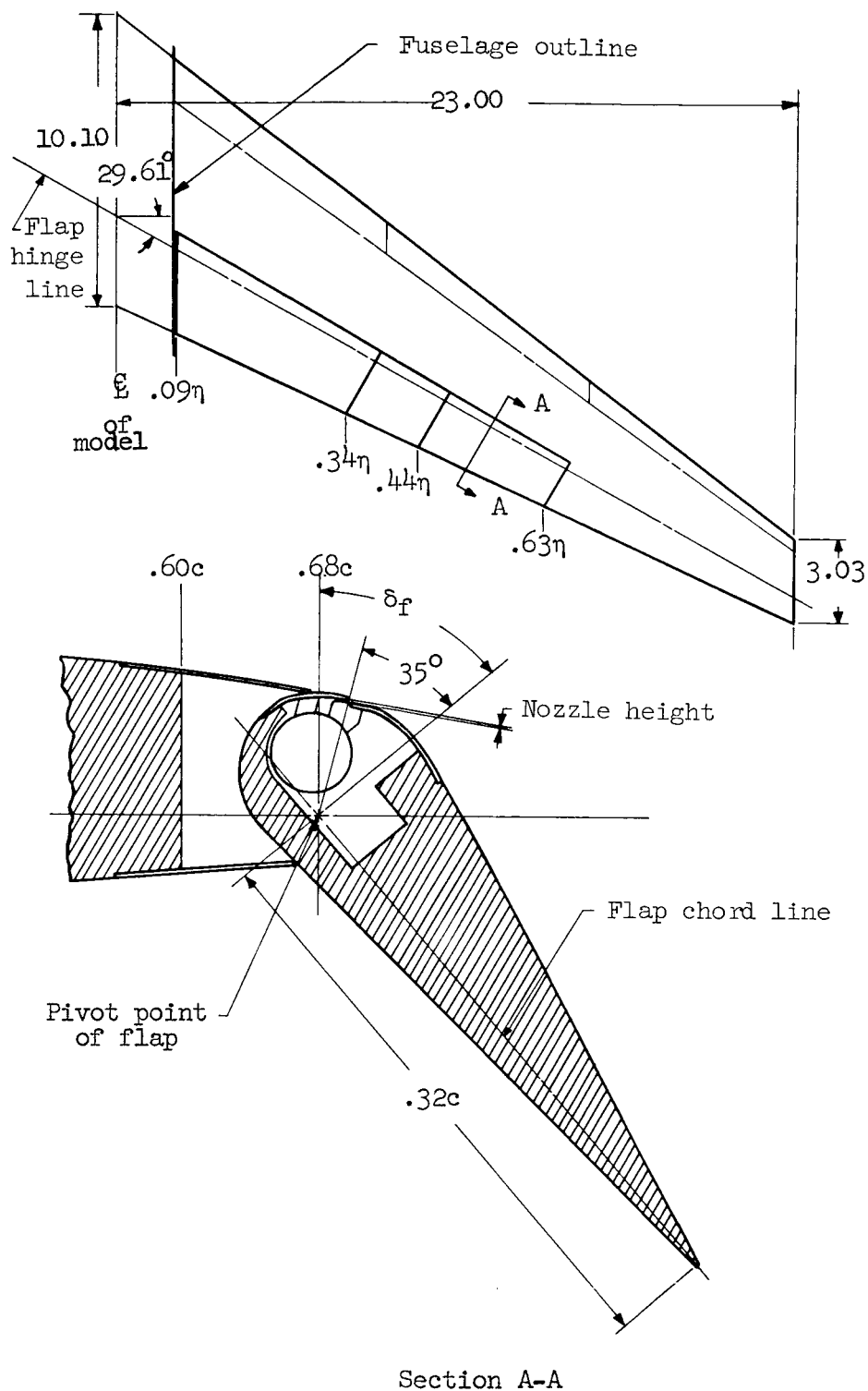


Figure 5.- Details of the trailing-edge flap.

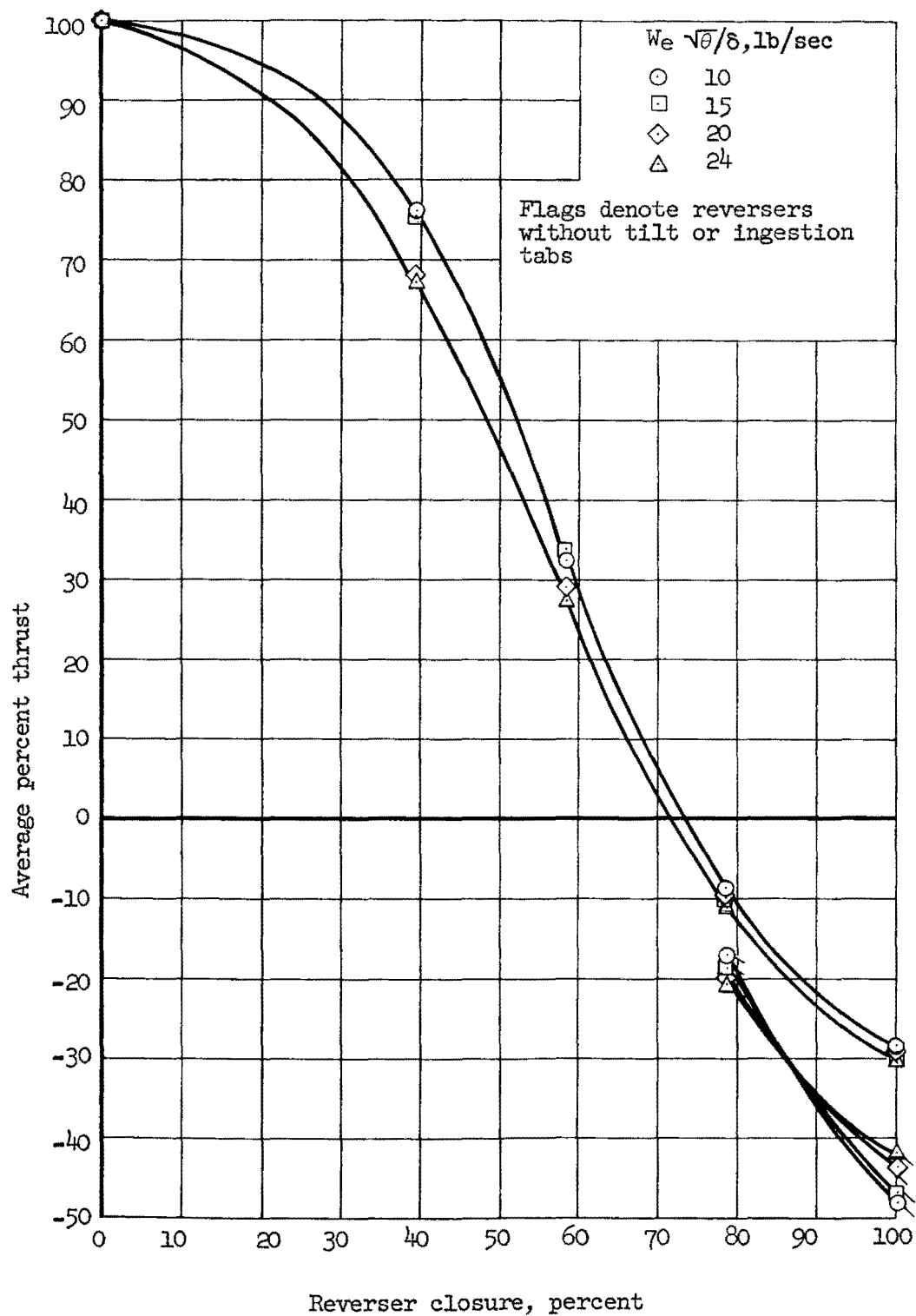
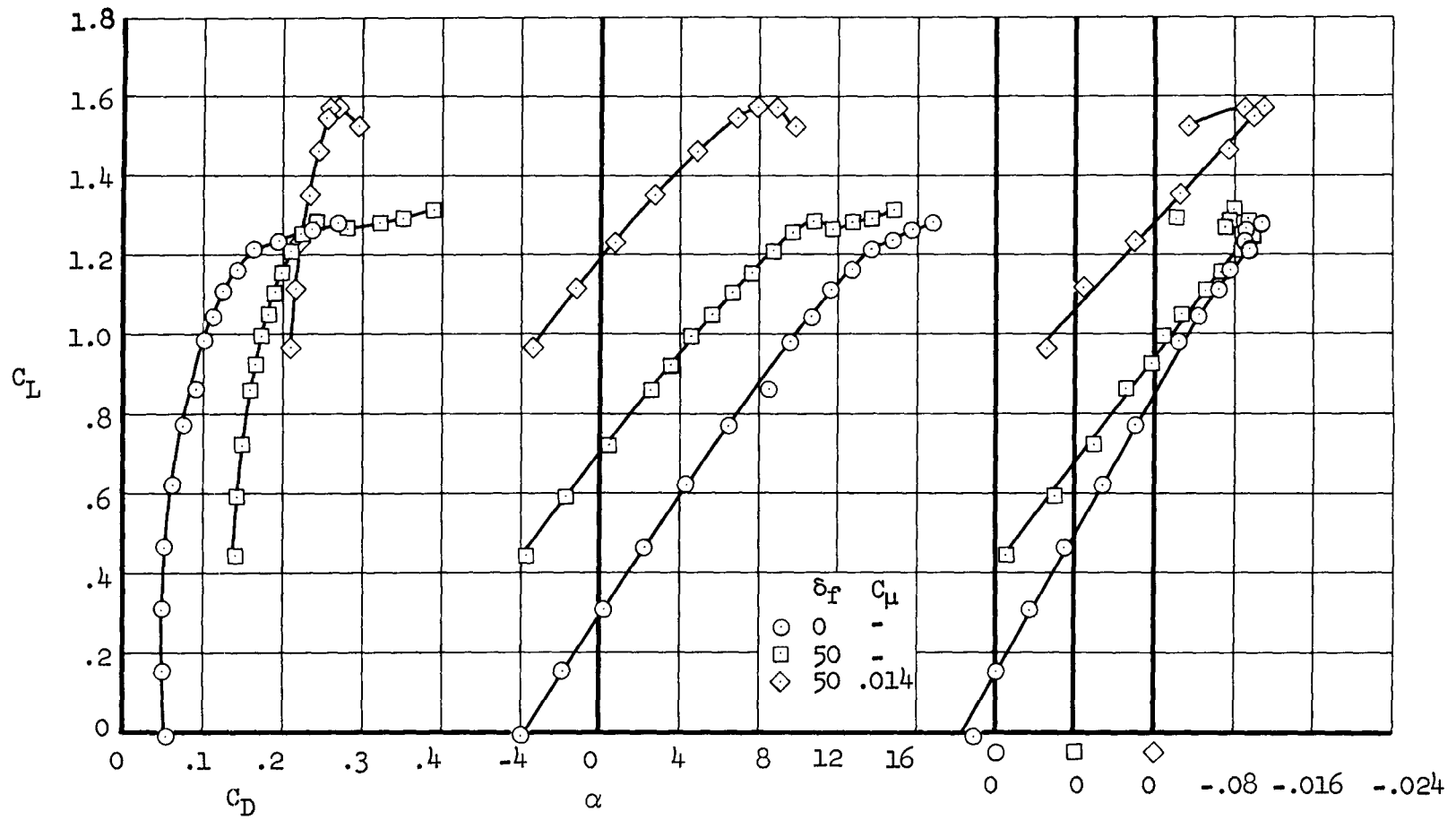
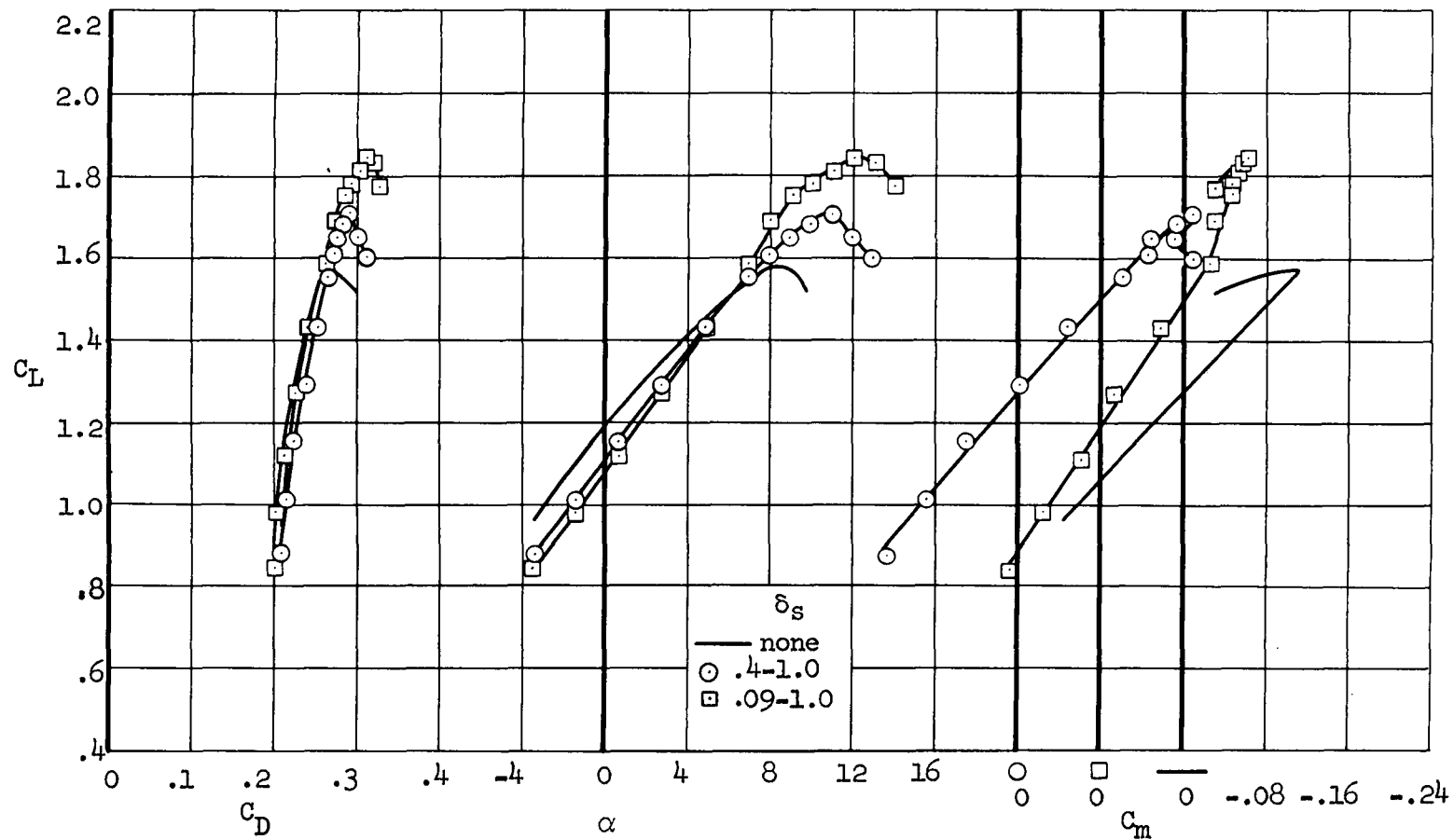


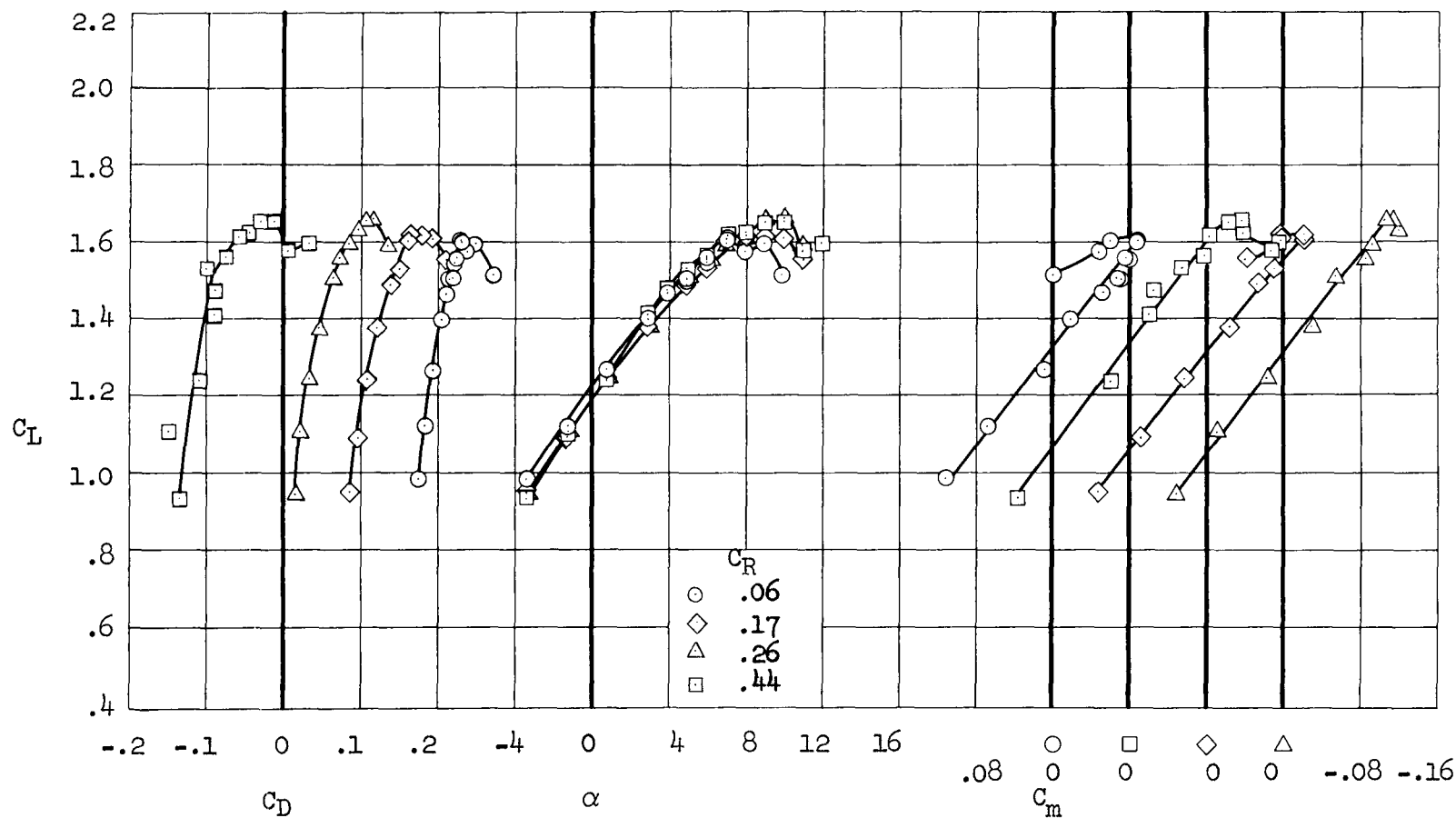
Figure 6.- Effect of reverser closure on thrust for reverser configurations 1 and 2 at several power settings.





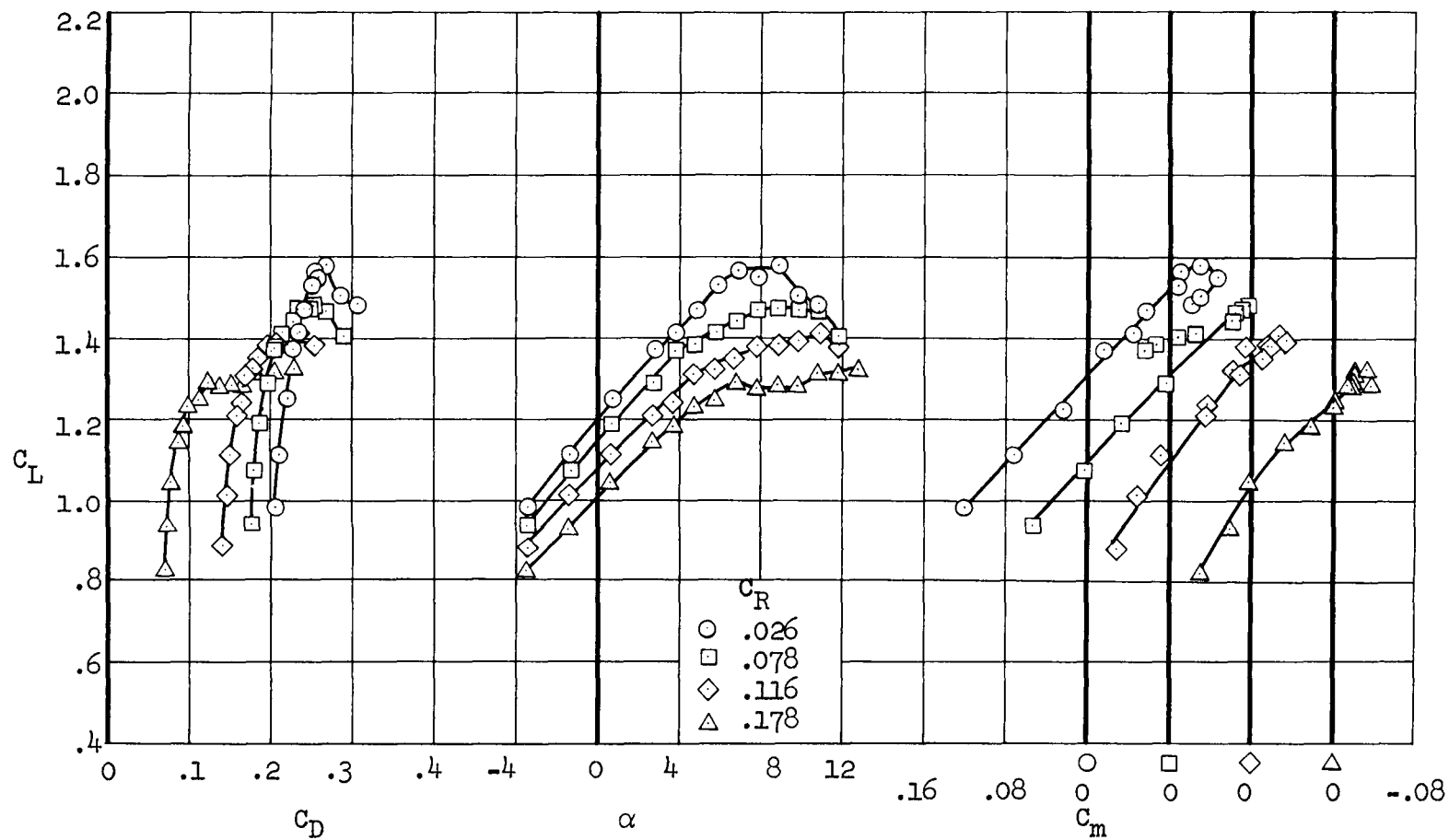
(b) Effect of leading-edge slats; $\delta_F = 50^\circ$; $C_{\mu} = 0.014$.

Figure 7.- Concluded.



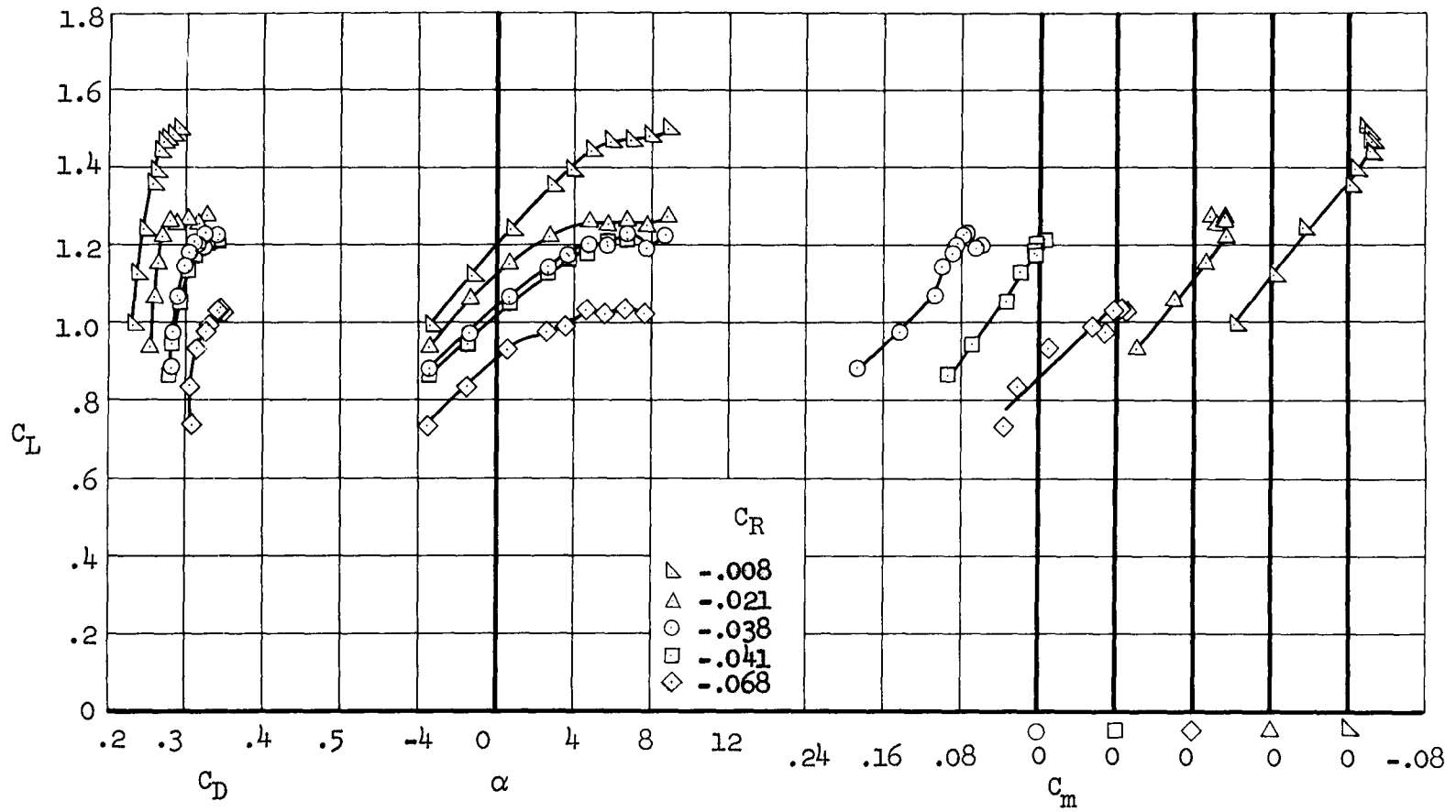
(a) Reverser closure 40 percent.

Figure 8.- Effect of power and reverser closure on longitudinal characteristics; plain leading edge
 $\delta_F = 50^\circ$; $C_\mu = 0.014$; reverser configuration 2.



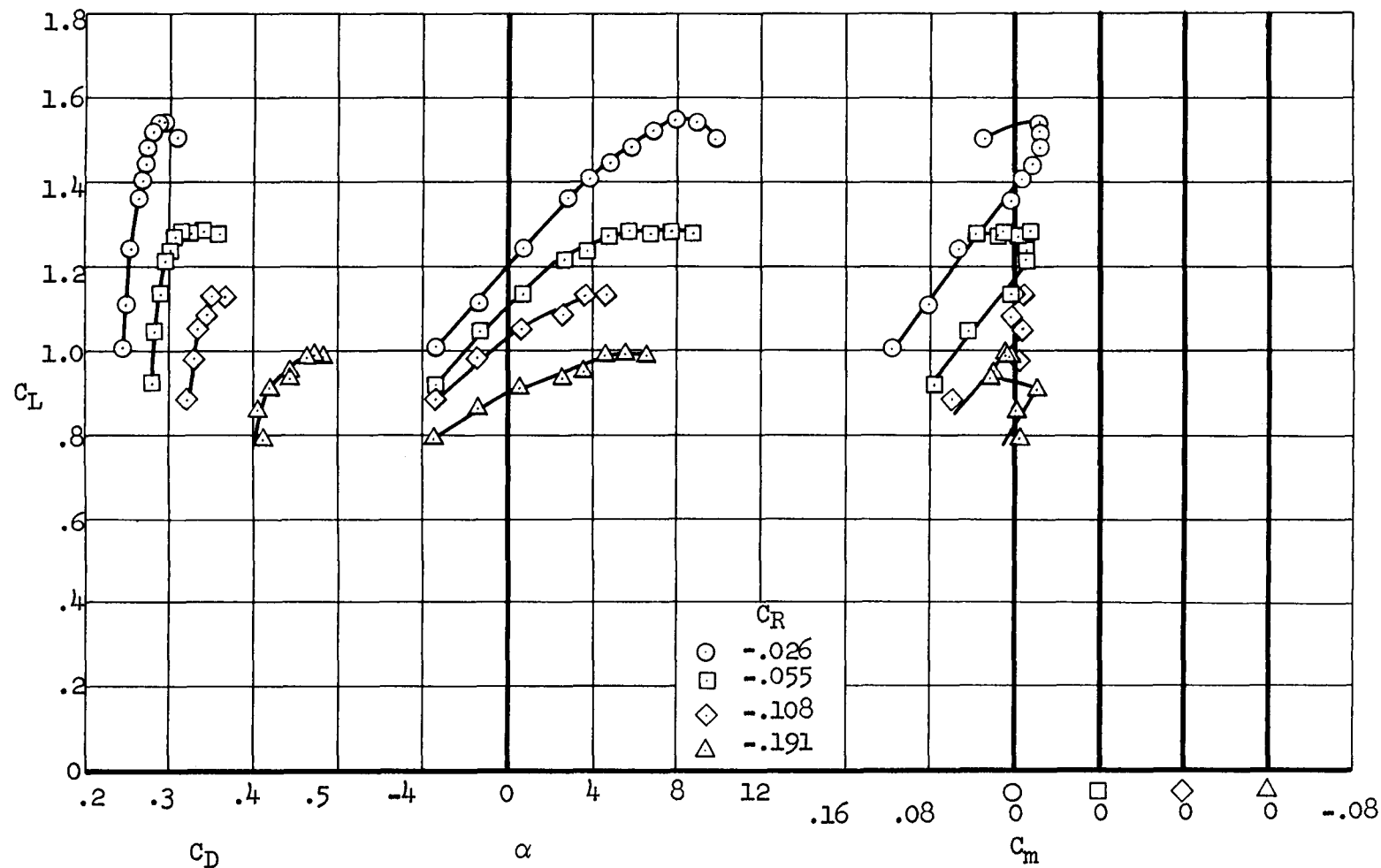
(b) Reverser closure 58 percent.

Figure 8.- Continued.



(c) Reverser closure 79 percent.

Figure 8.- Continued.



(d) Reverser closure 100 percent.

Figure 8.- Concluded.

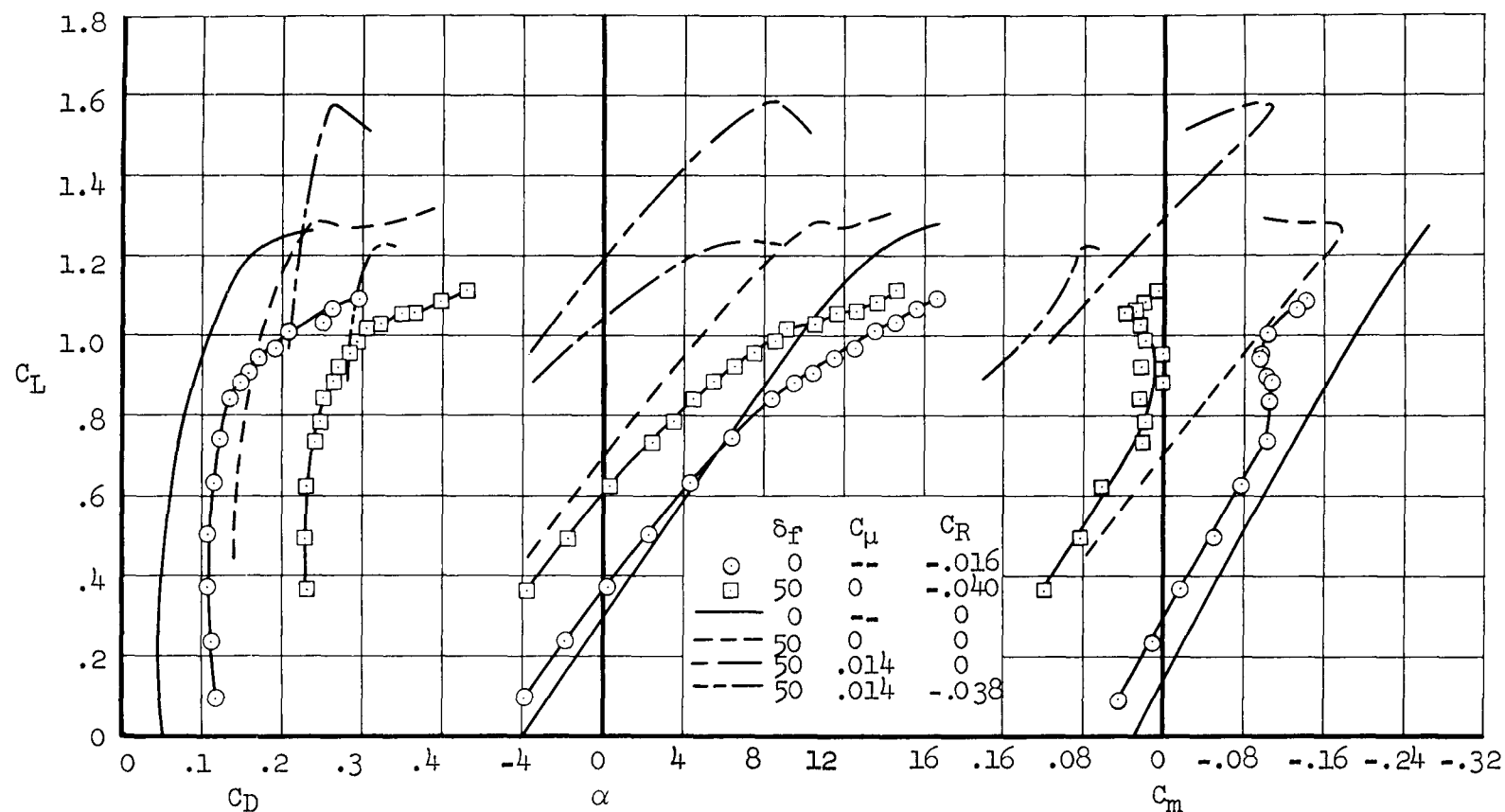


Figure 9.- Effect of reverser operation on longitudinal characteristics with and without high-lift devices; plain leading edge; 79-percent reverser closure; reverser configuration 2.

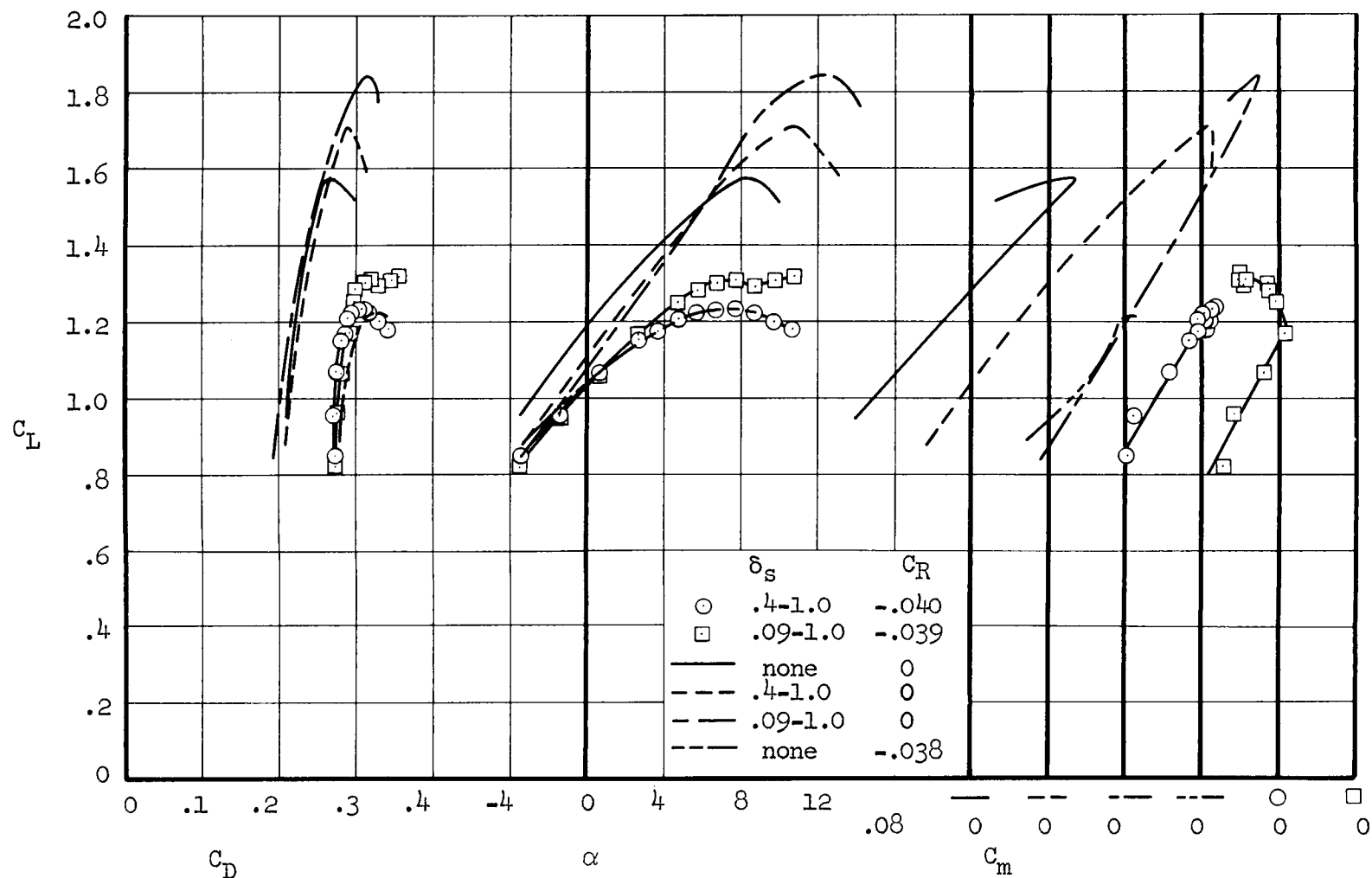


Figure 10.- Effect of reverter operation on longitudinal characteristics with leading-edge slats; 79-percent reverter closure; $\delta_F = 50^\circ$; $C_\mu = 0.014$; reverter configuration 2.

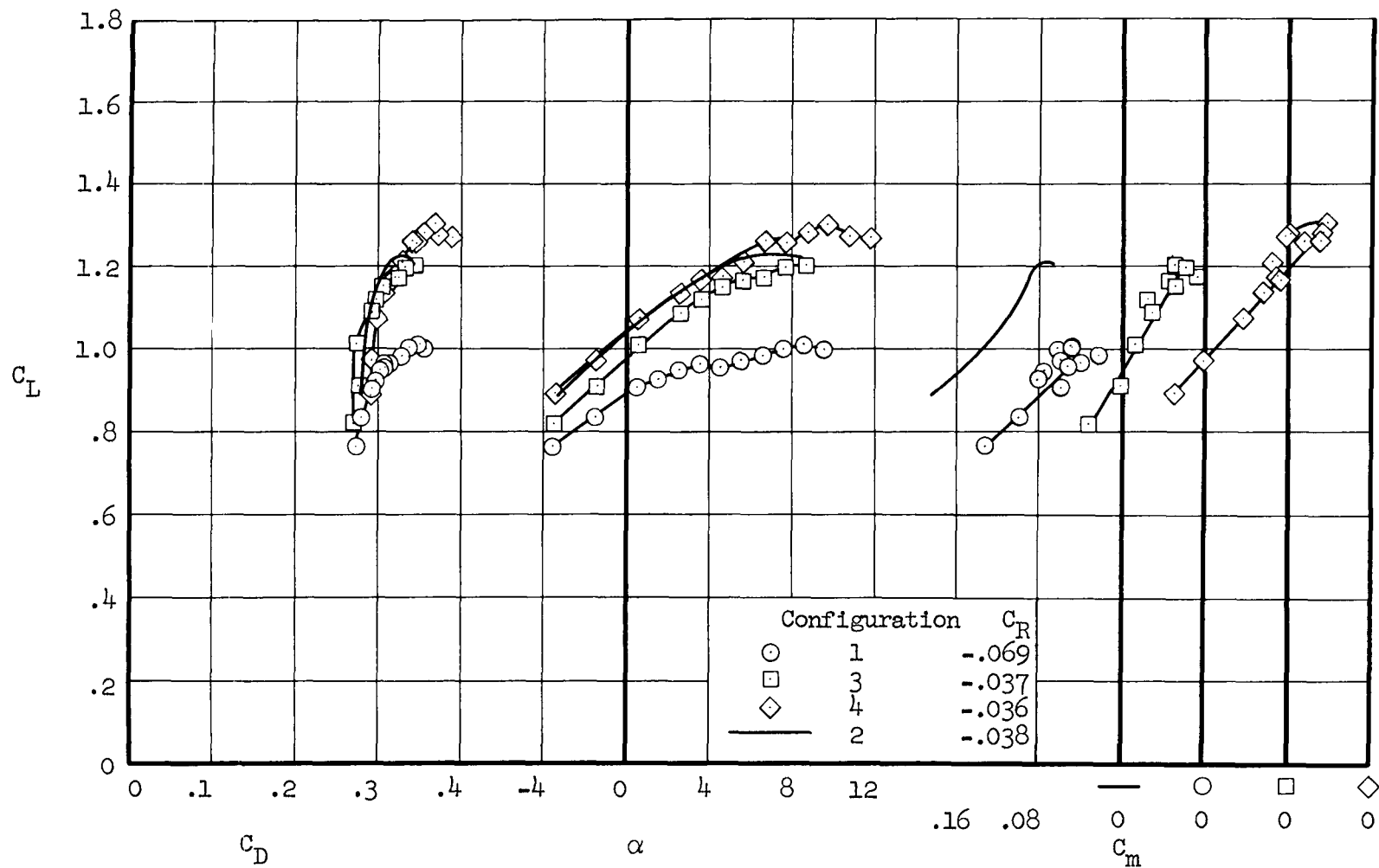


Figure 11.- Effect of reverser configuration on longitudinal characteristics; plain leading edge; 79-percent reverser closure; $\delta_f = 50^\circ$; $C_\mu = 0.014$; $W_e \sqrt{\theta/\delta} = 18$ lb/sec per engine.

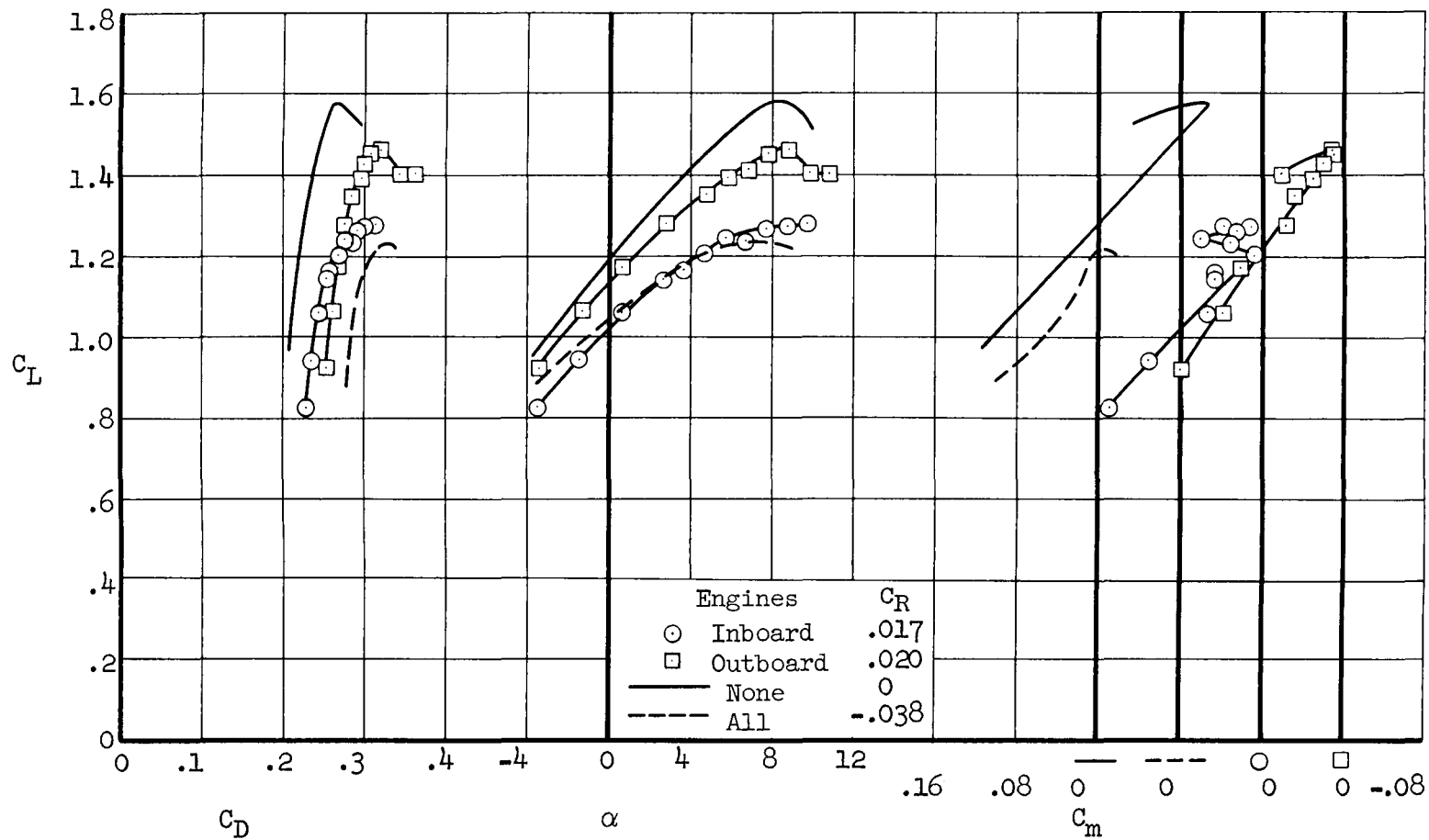


Figure 12.- Effect of symmetrical two-reverser operation on longitudinal characteristics; 79-percent reverser closure; plain leading edge; $\delta_F = 50^\circ$; $C_\mu = 0.014$; reverse configuration 2; $W_e \sqrt{\theta/\delta} = 18$ lb/sec.

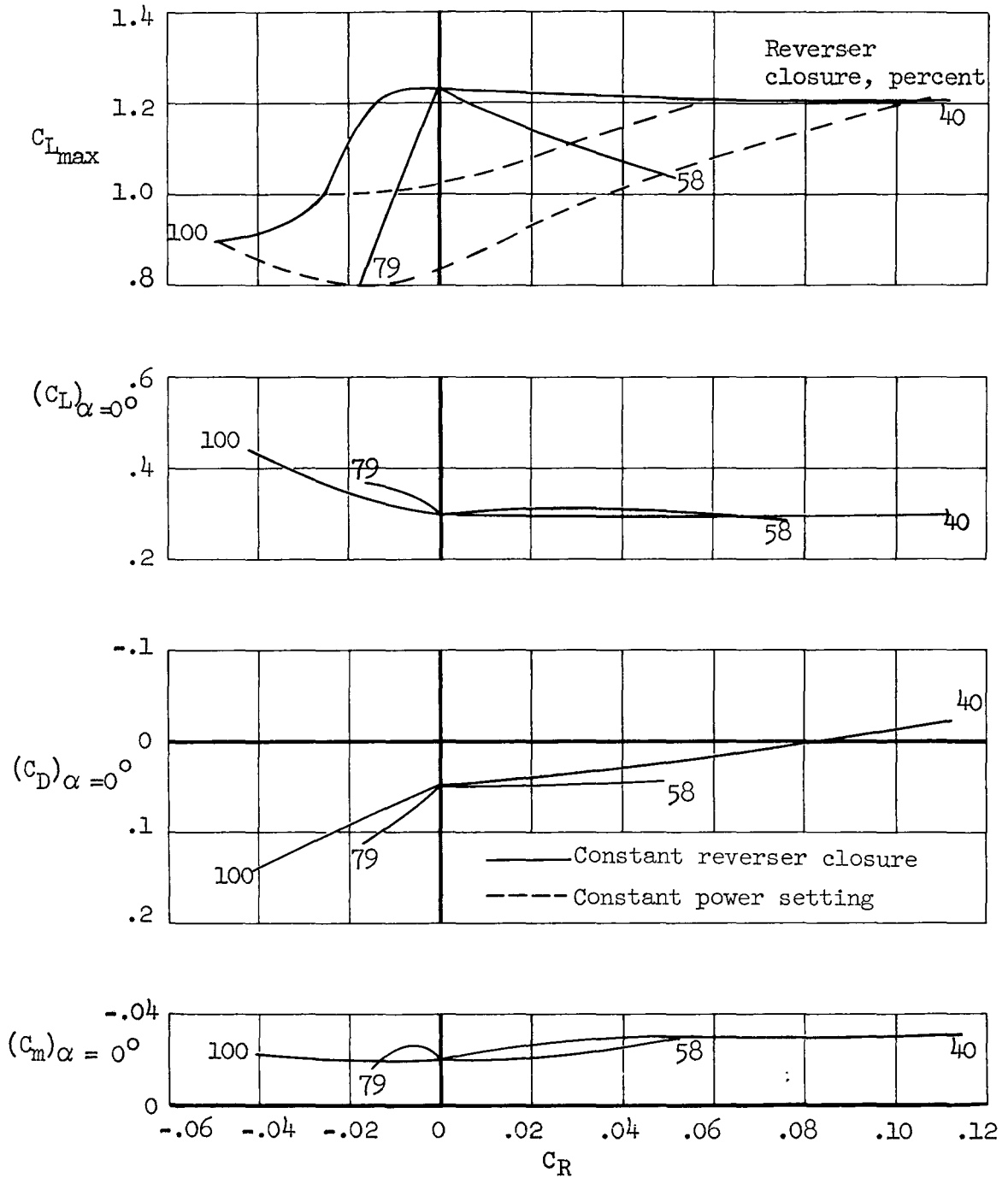
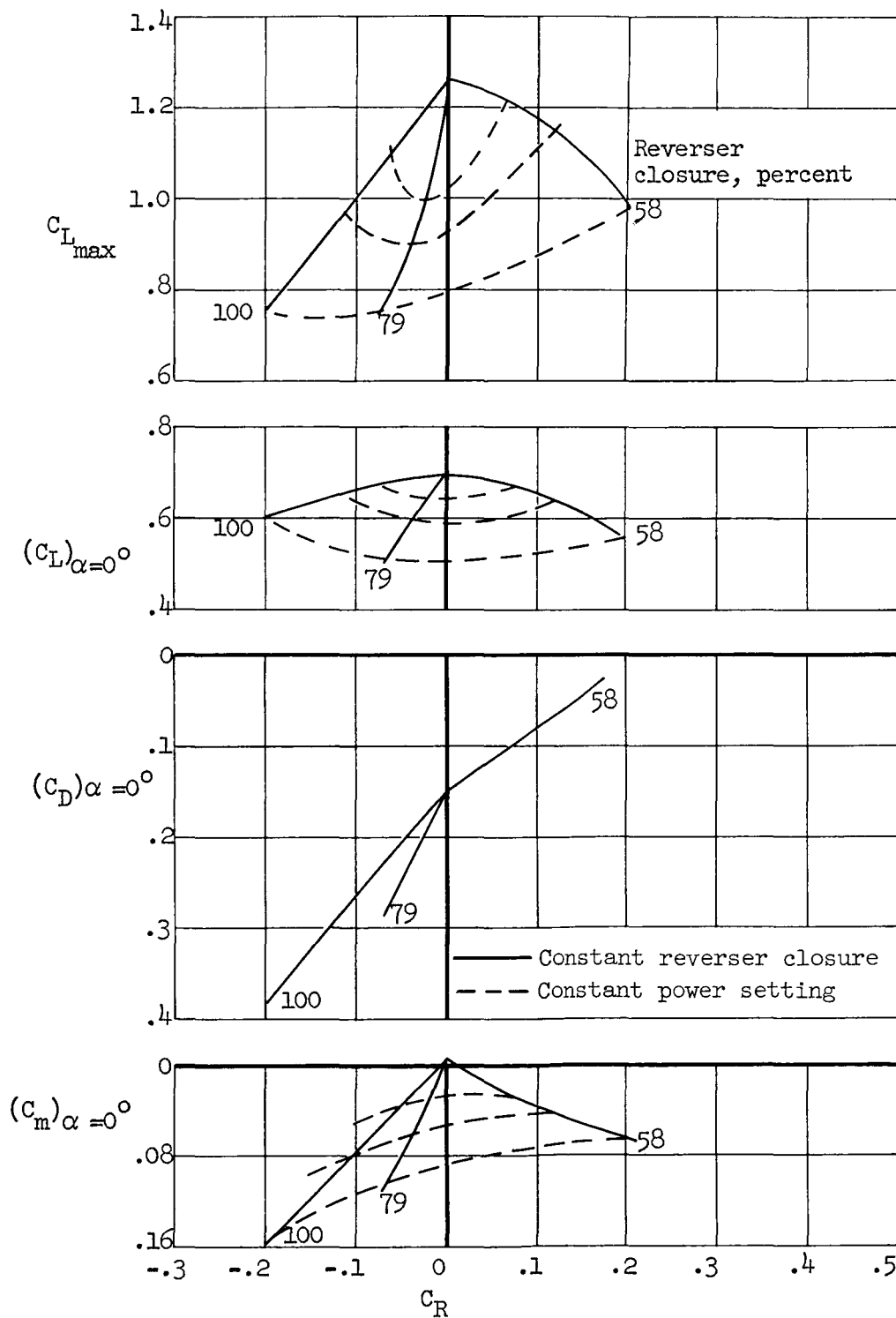
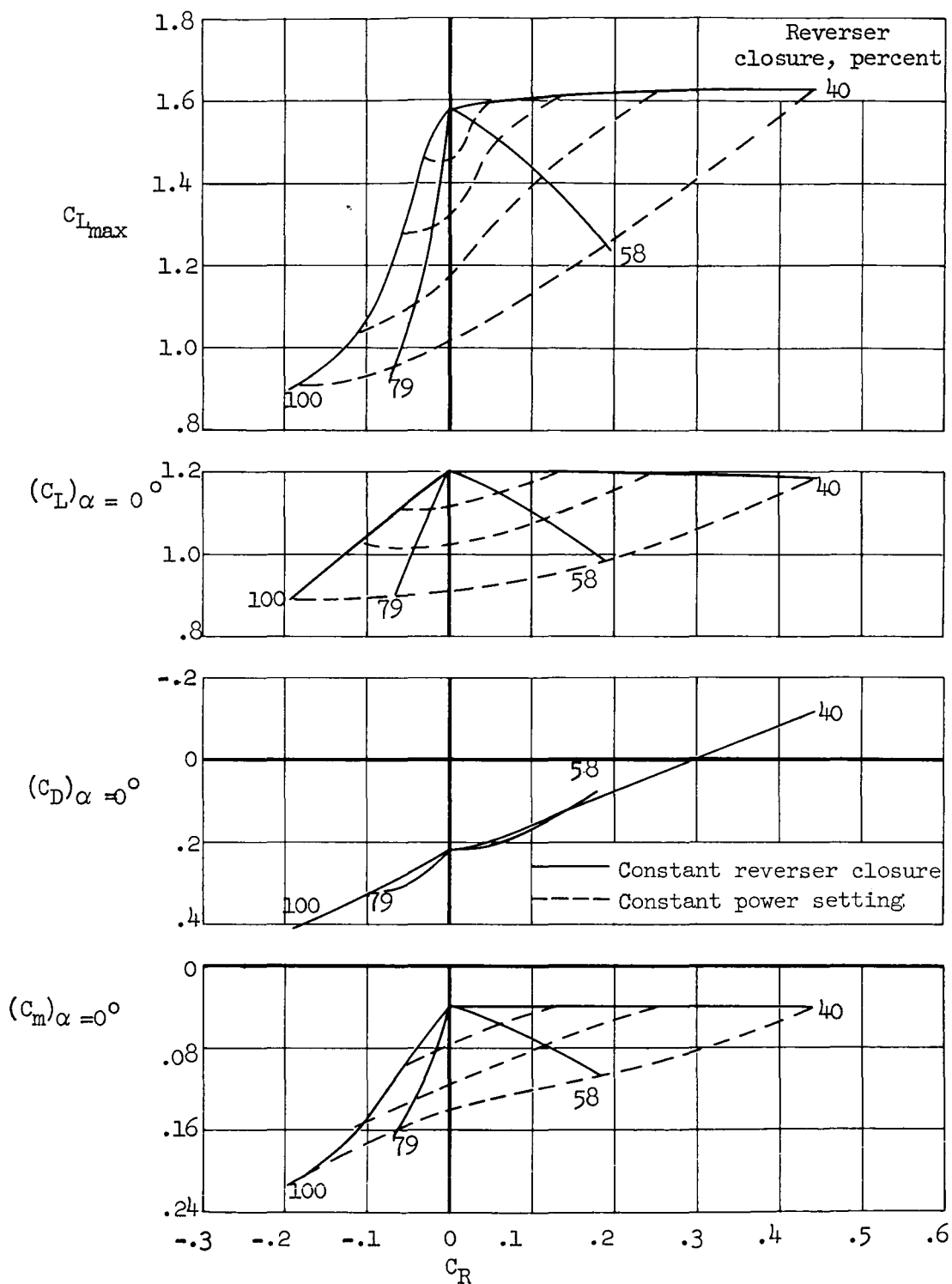
(a) $\delta_F = 0^\circ$

Figure 13.- Effect of power setting and reverser closure on longitudinal characteristics with several trailing-edge configurations, reverser configuration 2.



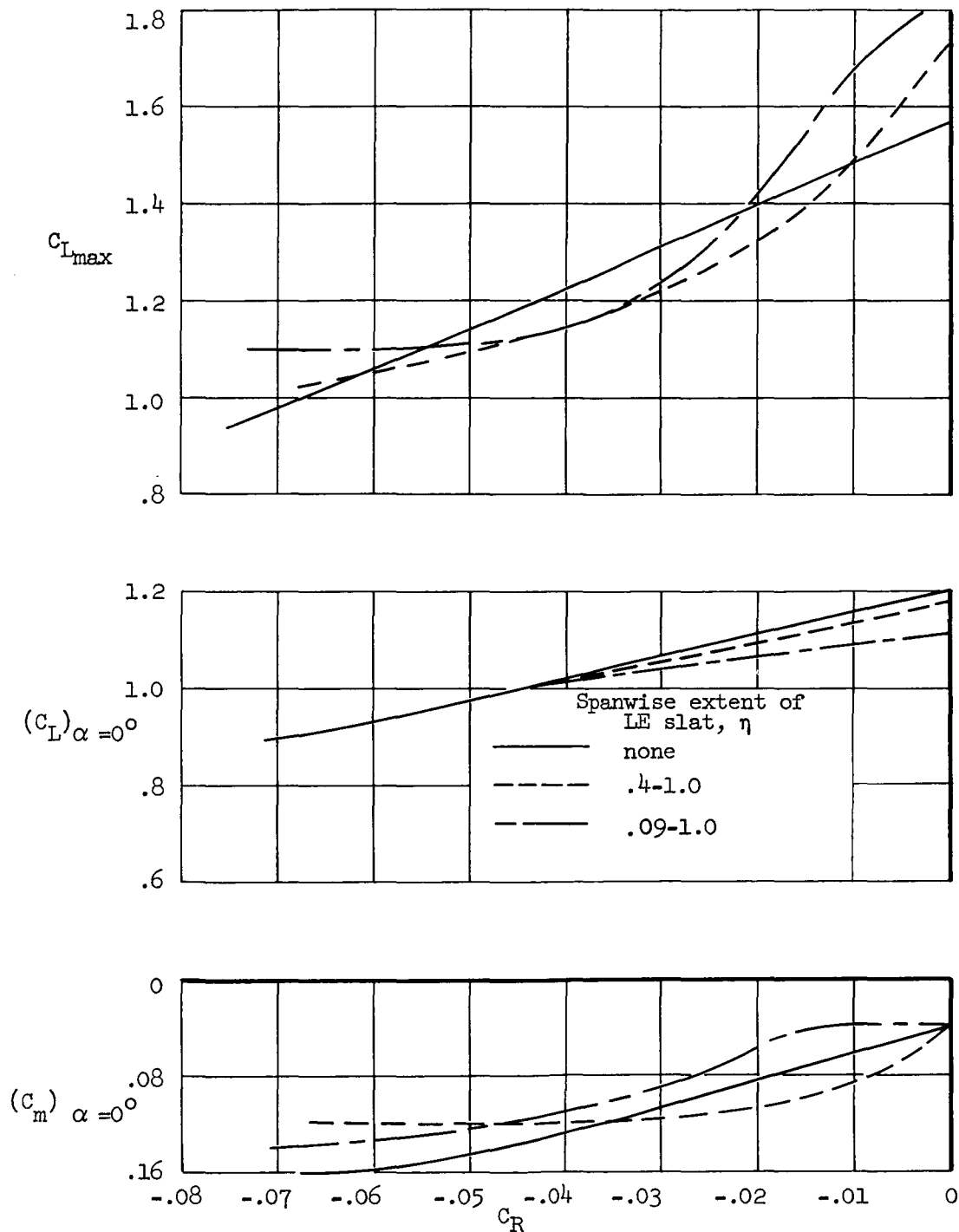
(b) $\delta_F = 50^\circ$; $C_\mu = 0$

Figure 13.- Continued.



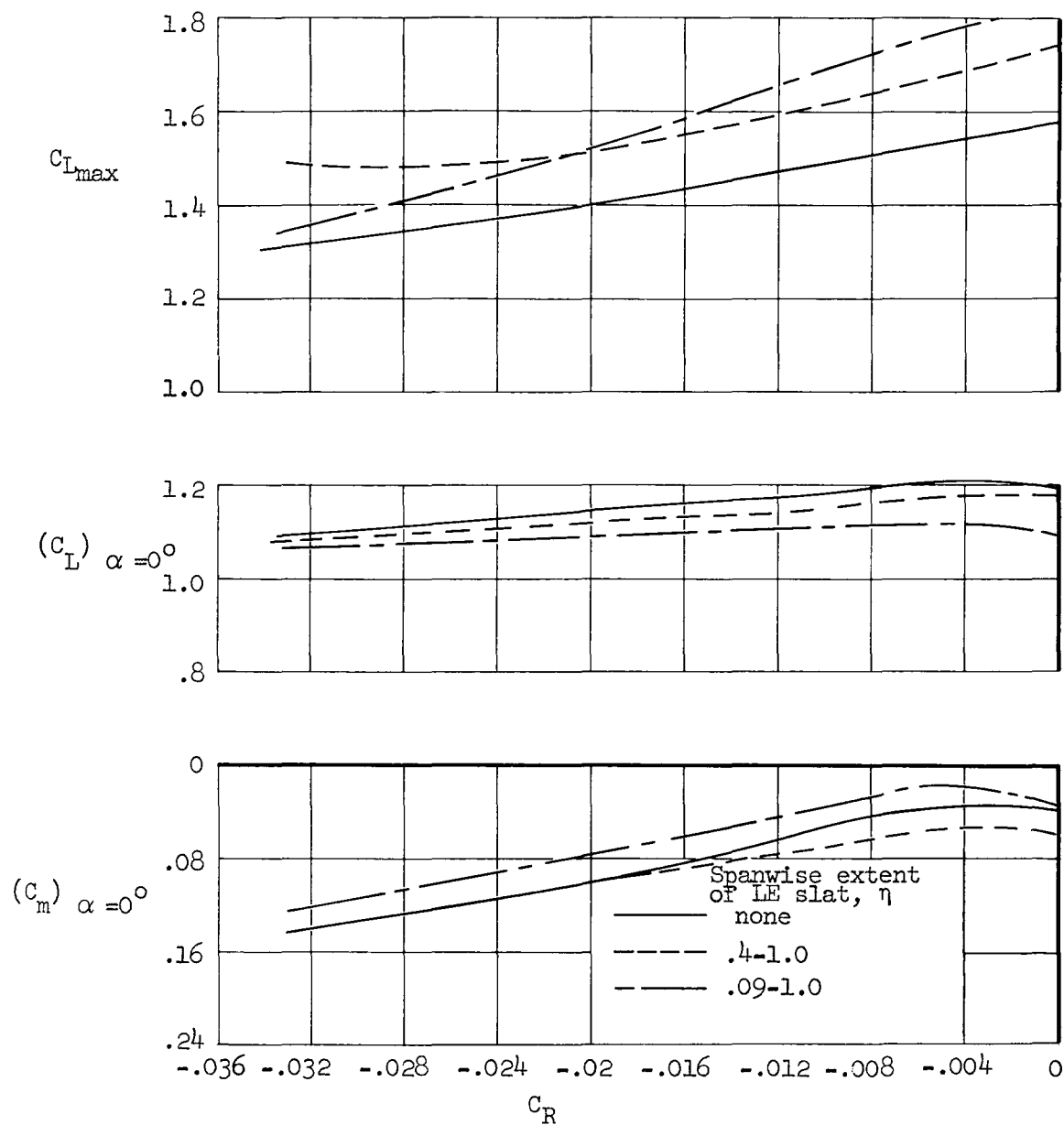
(c) $\delta_F = 50^\circ$; $C_\mu = 0.014$

Figure 13.- Concluded.



(a) Four engines.

Figure 14.- Effect of power setting on longitudinal characteristics with several leading-edge configurations; 79-percent reverser closure; reverser configuration 2; $\delta_f = 50^\circ$; $C_\mu = 0.014$.



(b) Outboard engines only.

Figure 14.- Concluded.

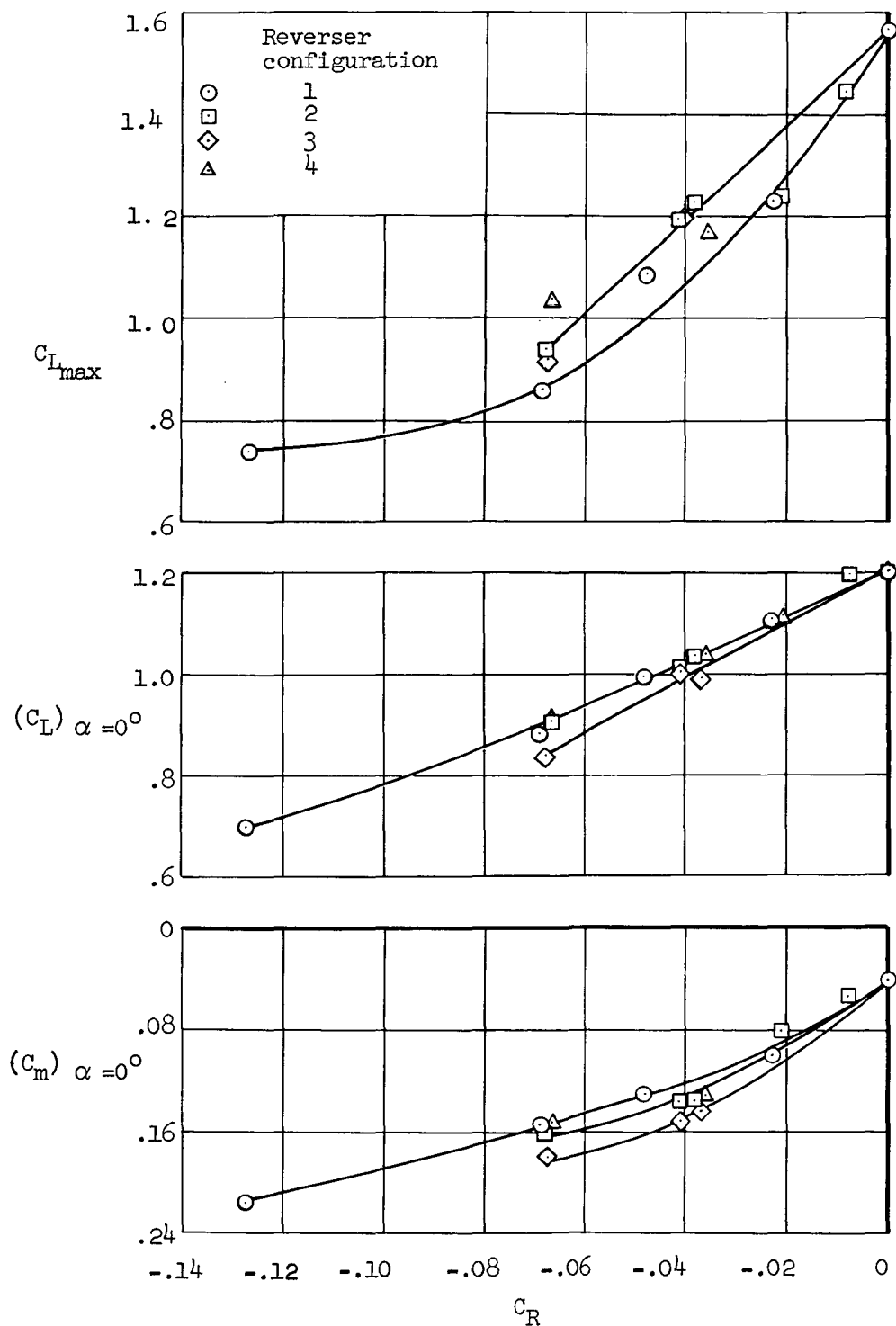
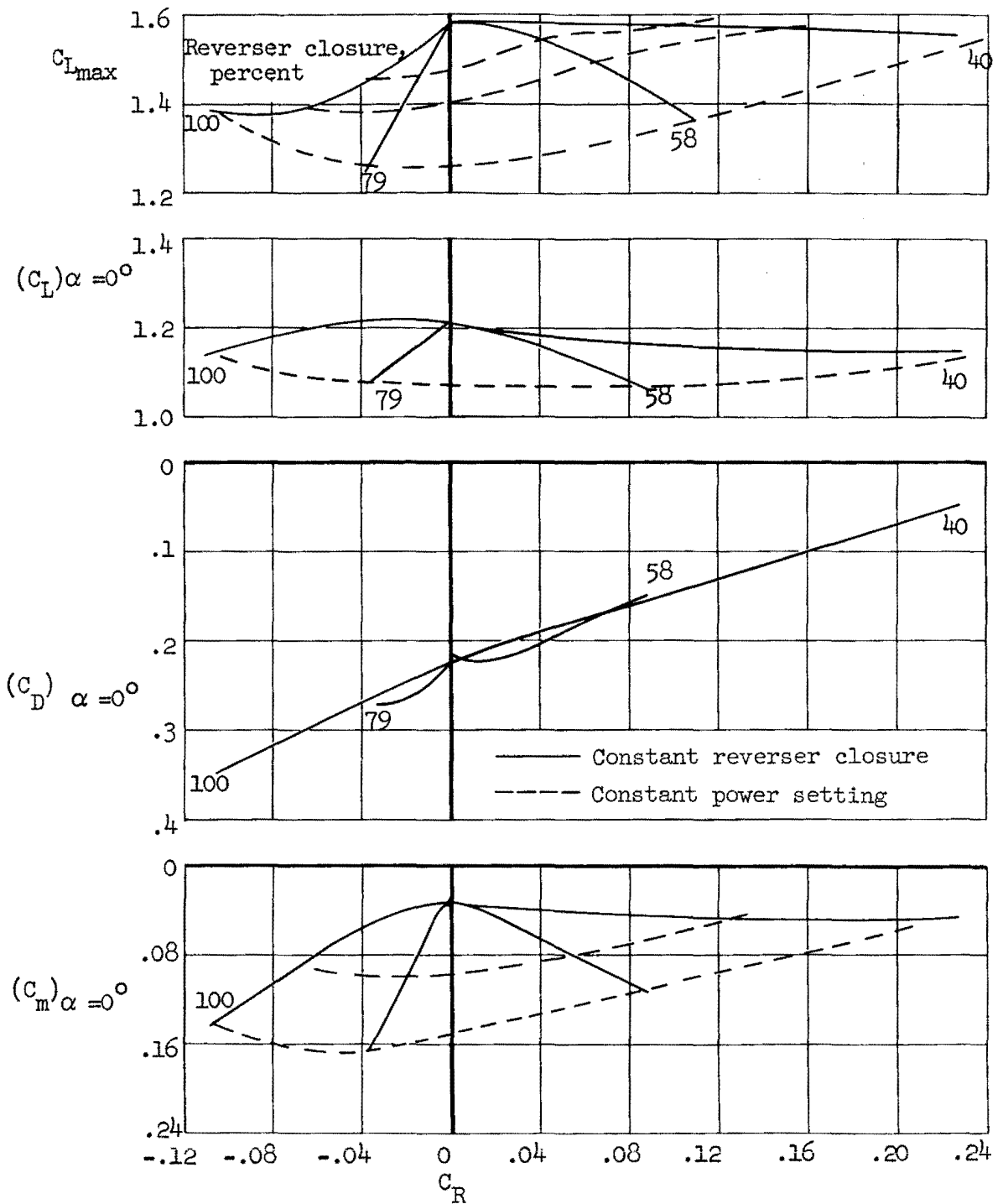
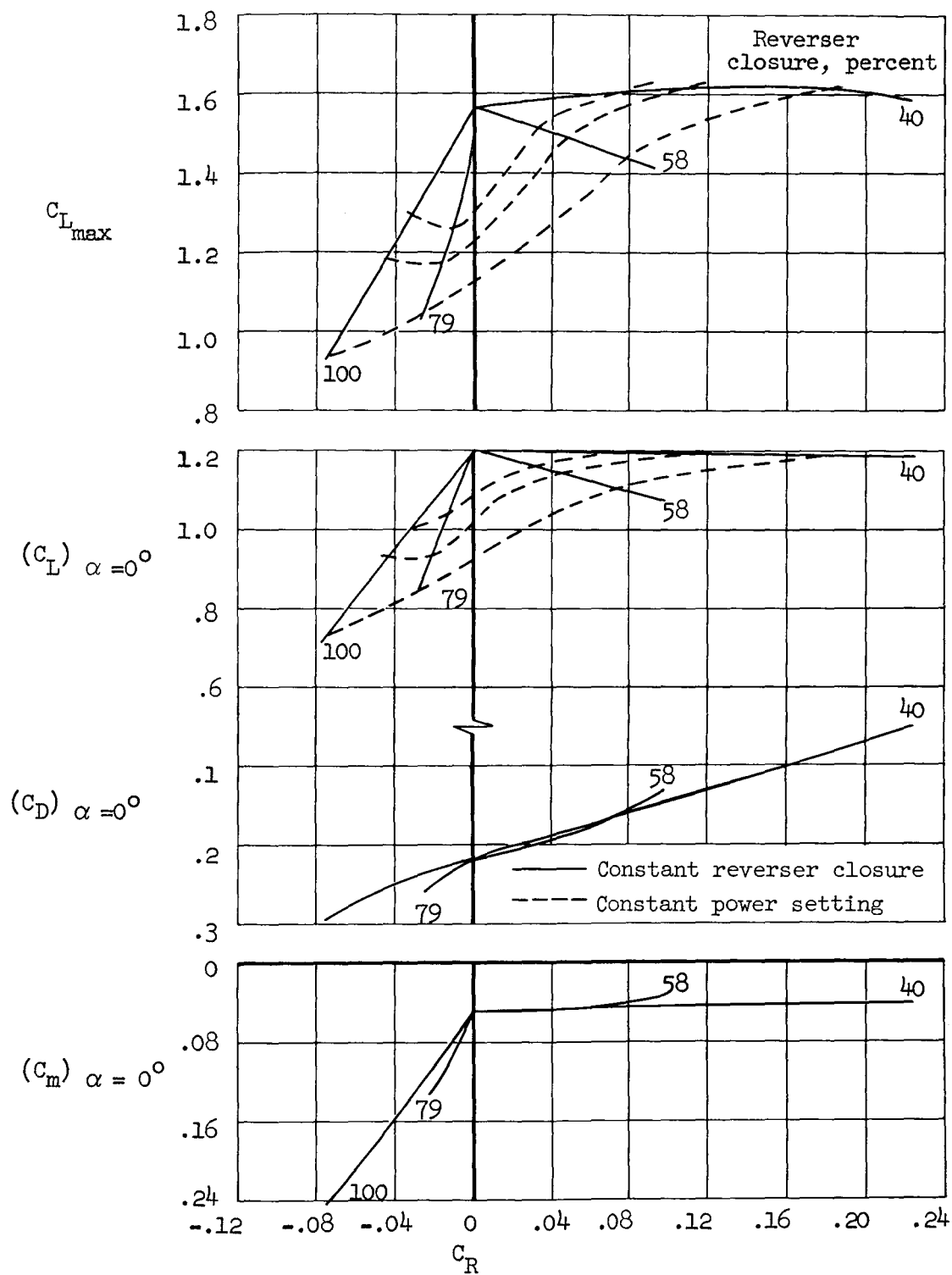


Figure 15.- Effect of power setting and reverser configuration on longitudinal characteristics; four engines; 79-percent reverser closure; $\delta_F = 50^\circ$; $C_\mu = 0.014$.



(a) Outboard engines.

Figure 16.- Effect of power setting and reverser closure on longitudinal characteristics with two engines operating; $\delta_F = 50^\circ$; $C_{\mu} = 0.014$.



(b) Inboard engines.

Figure 16.- Concluded.

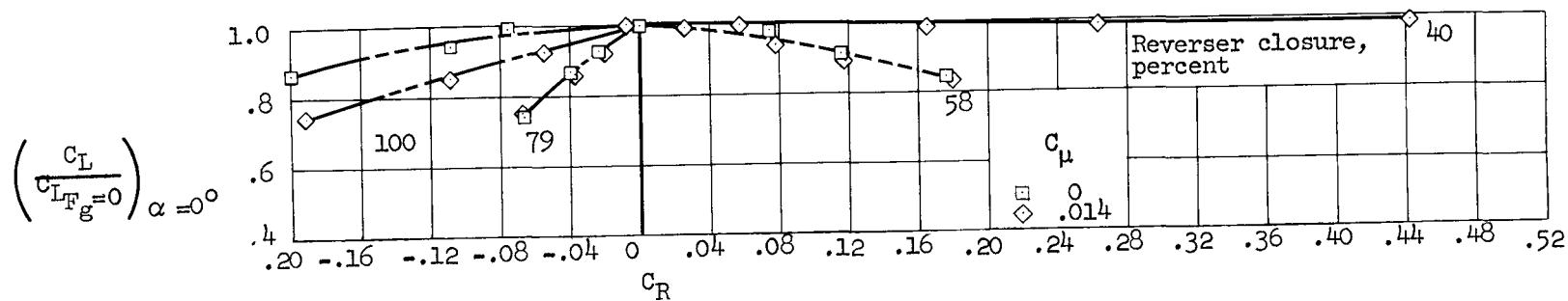
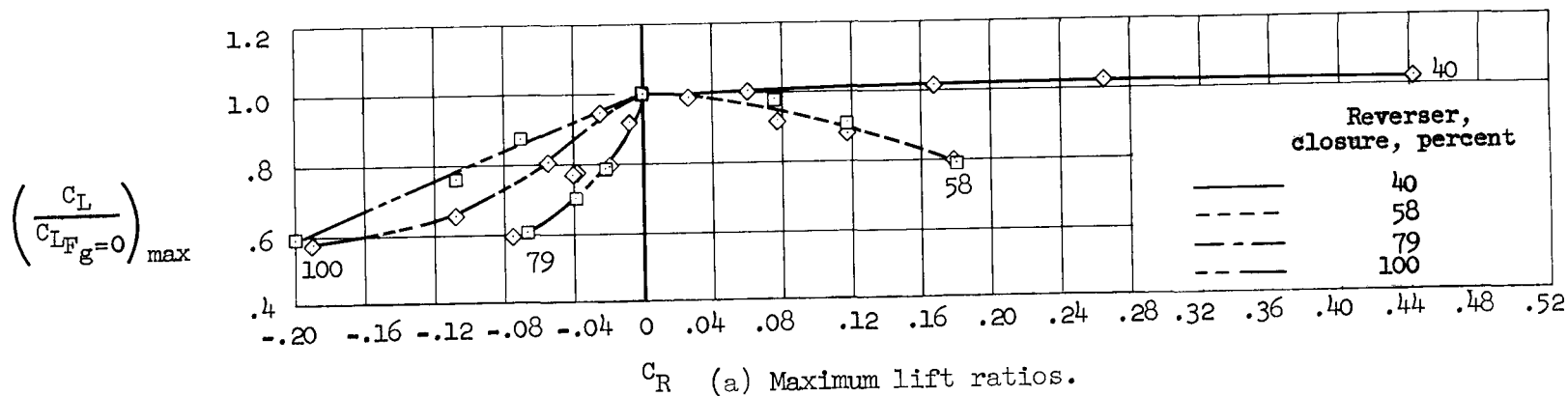
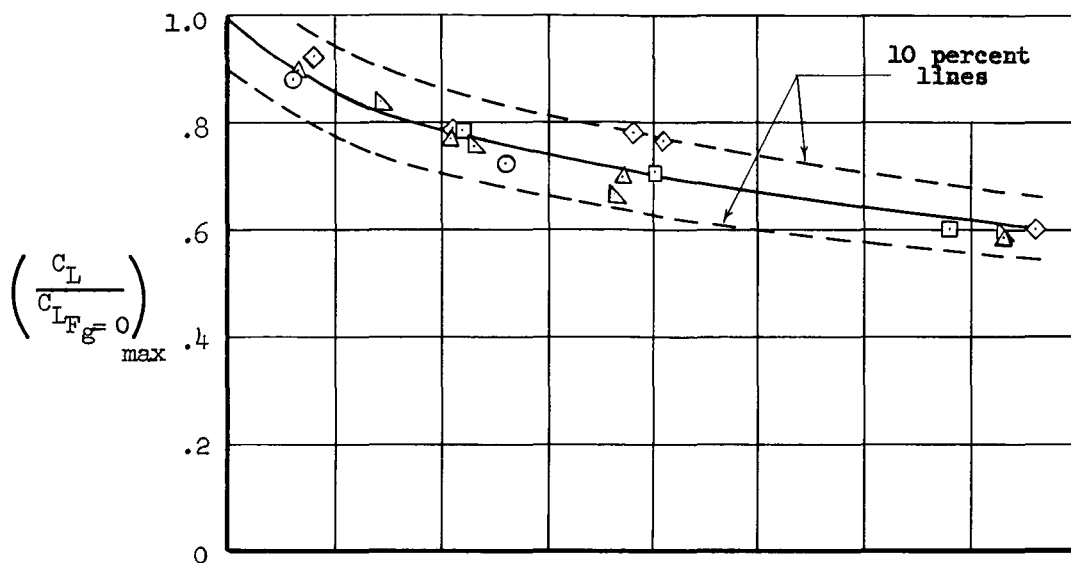


Figure 17.- Power-on to power-off lift ratio variation with reversed thrust coefficient; four engines operating; plain leading edge; $\delta_f = 50^\circ$.



(a) Maximum lift ratio.

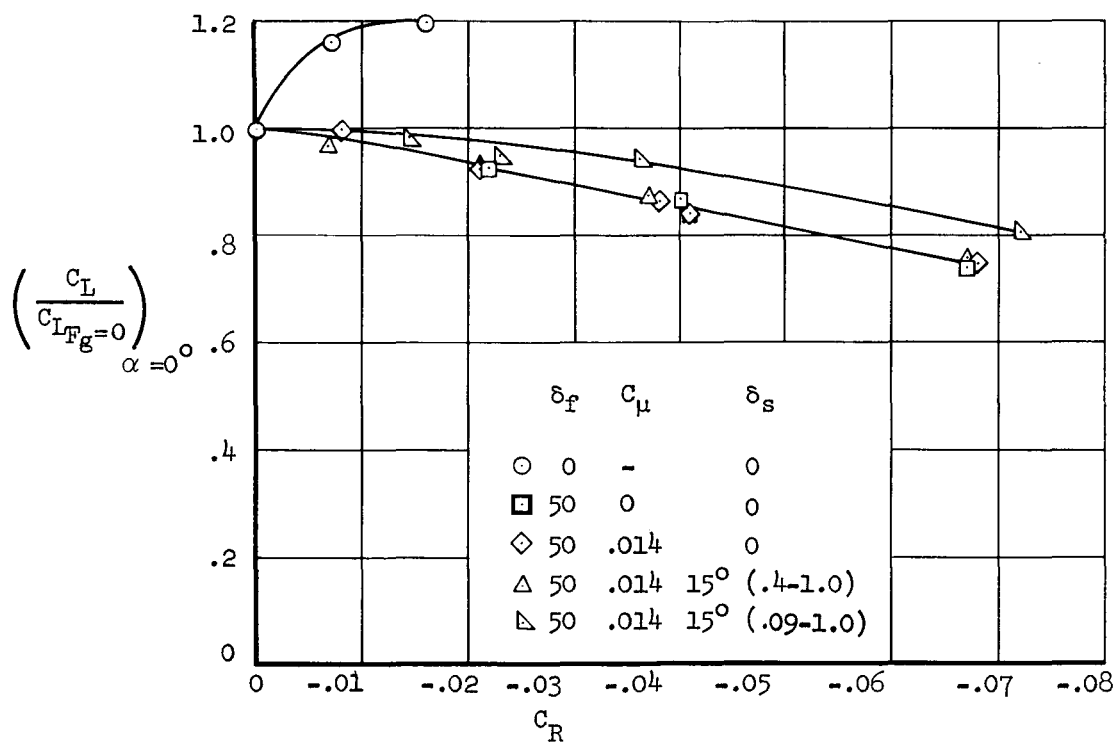
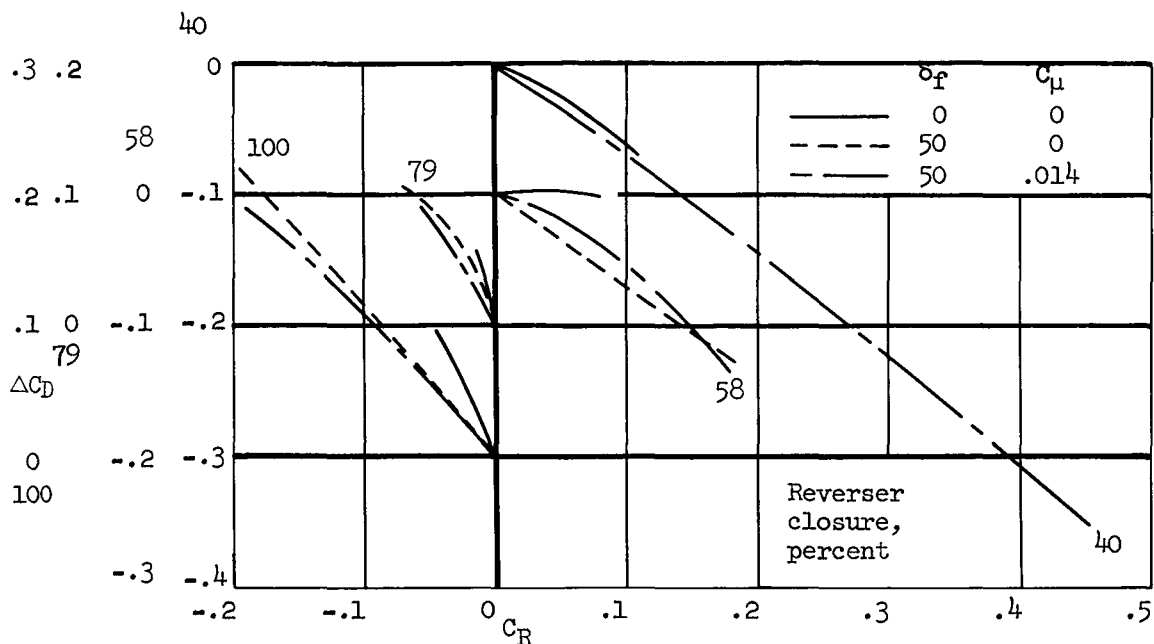
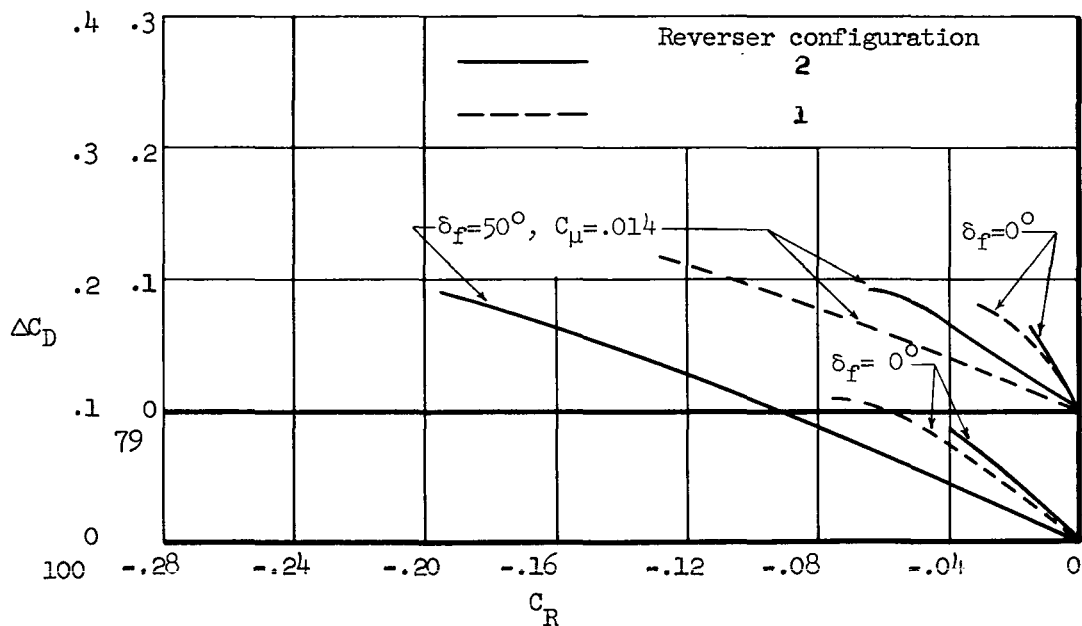
(b) Lift-ratio at $\alpha = 0^\circ$.

Figure 18.- Power-on to power-off lift ratio variation with reversed thrust coefficient for several leading- and trailing-edge configurations, 79-percent reverser closure.

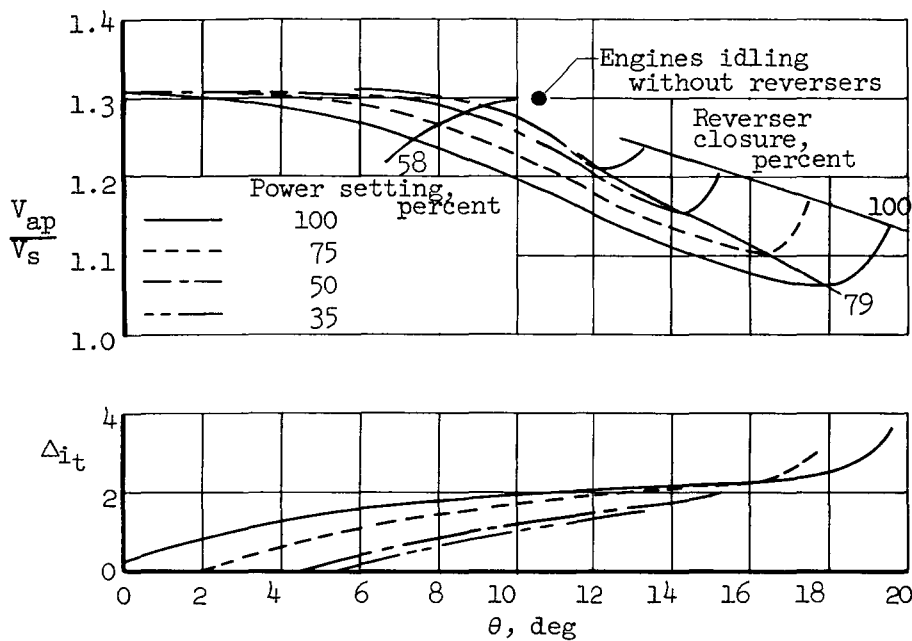
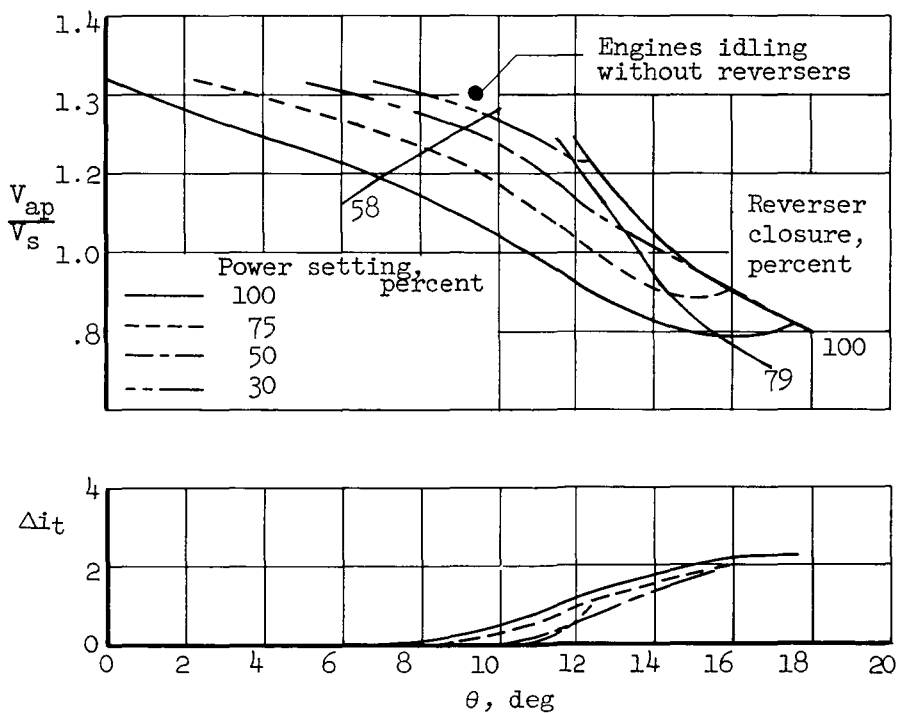


(a) Effect of flap deflection; reverser configuration 2.



(b) Effect of ingestion tabs with reverser closures of 79 and 100 percent.

Figure 19.- The effect of reverser operation on model drag coefficient;
 $\alpha = 0^\circ$.

(a) $V = 140$ knots.(b) $V = 120$ knots.Figure 20.- Effect of reverser closure and power setting on approach speed margin; $W/S = 65$ lb/sq ft.

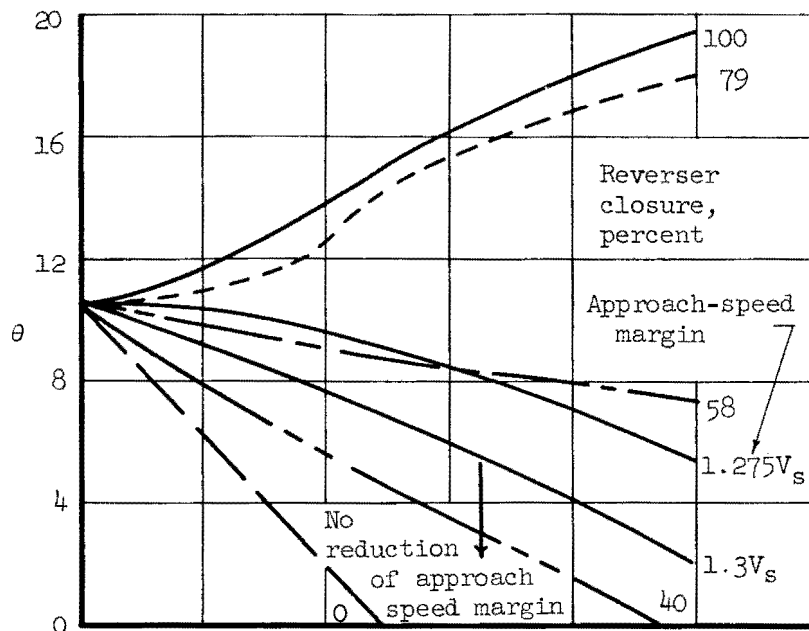
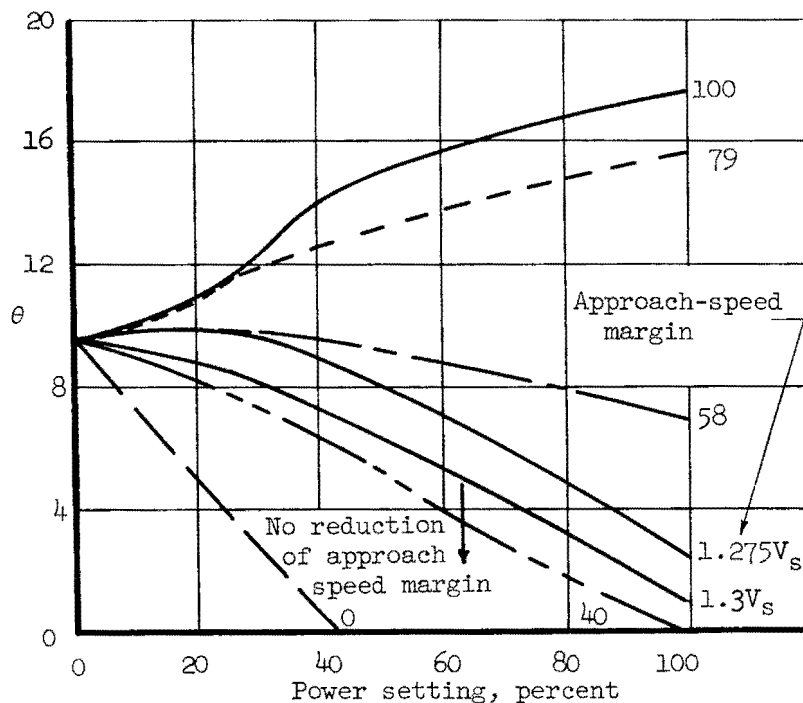
(a) $V = 140$ knots.(b) $V = 120$ knots.

Figure 21.- The variation of descent angle with power setting for several reverser closures; $W/S = 65$ lb/sq ft.